$\Phi^*\mathrm{A}\ \theta_W$

Electroweak Honor Society

Scholarship

Leadership

Service

DØ Precision Measurements of EW Bosons from Birth to Death

Breese Quinn

University of Mississippi

Fermilab Wine & Cheese Seminar

November 14, 2014

Induction Ceremony

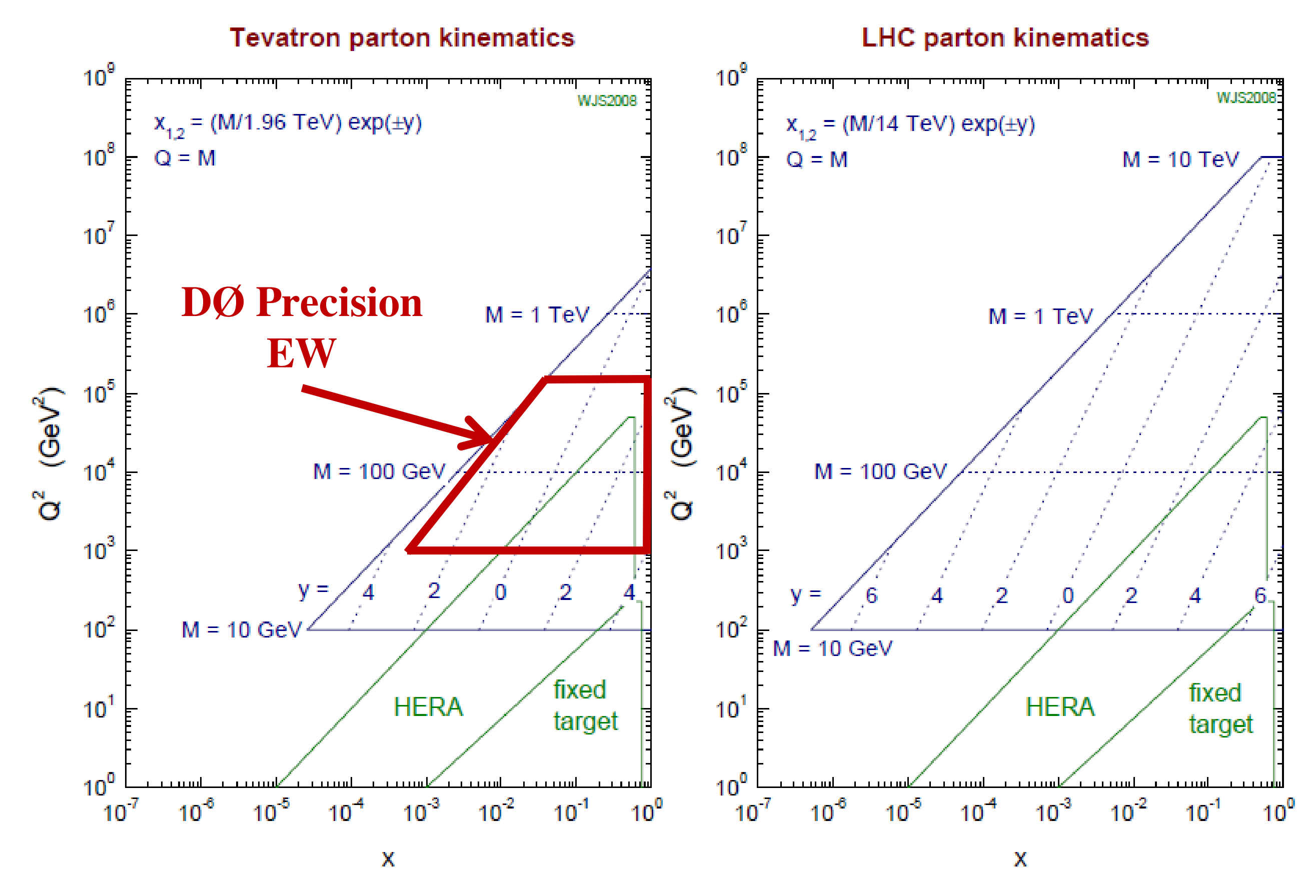
- History of the Society

Candidates for Induction

- ϕ^*: Birth of a Boson
  - Measurement of the ϕ^* distribution of muon pairs with masses between 30 and 500 GeV in 10.4 fb^{-1} of $p\bar{p}$ collisions
- A: Vectors from birth to death
  - Measurement of the electron charge asymmetry in $p\bar{p} \to W + X \to e\nu + X$ decays in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- θ_W: EW Mortality Statistics
  - Measurement of the effective weak mixing angle in $p\bar{p} \to Z/\gamma^* \to e^+e^-$ events

Why Precision EW?

- Need to understand proton structure better
- Kinematics coverage: For LHC, data fixed Q^2 spans wider x than the Tevatron

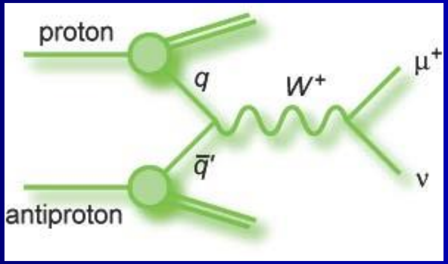


- Momentum transfer scale
  - $Q^2 \approx M_V^2$
- Parton momentum fraction
  - $x = \frac{M}{\sqrt{s}} e^{\pm y}$

  $0.002 < x < 1$
- Complementary to central and forward jet measurements at Tevatron, and other scattering expts.
  - Different systematics, couplings
  - Higher precision!

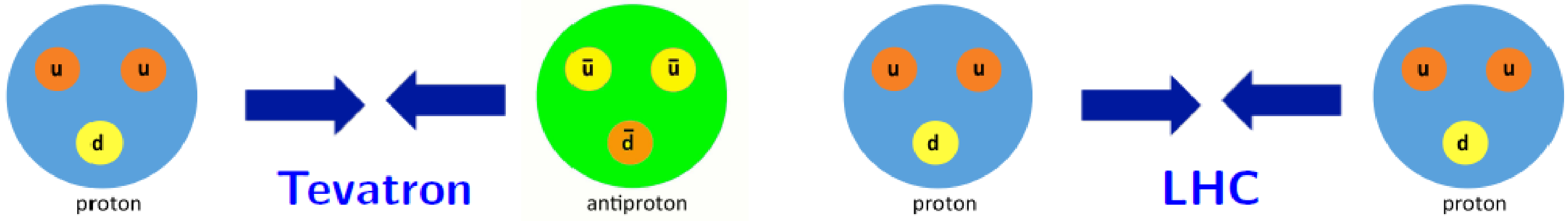
W Production at Tevatron/LHC

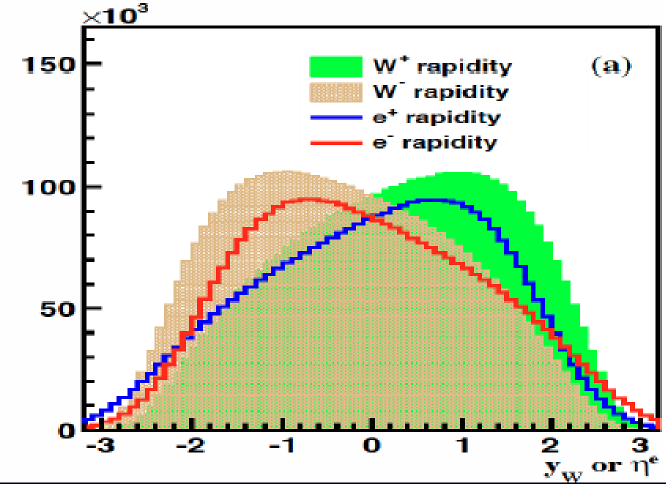
- Tevatron: dominated by valence quark production

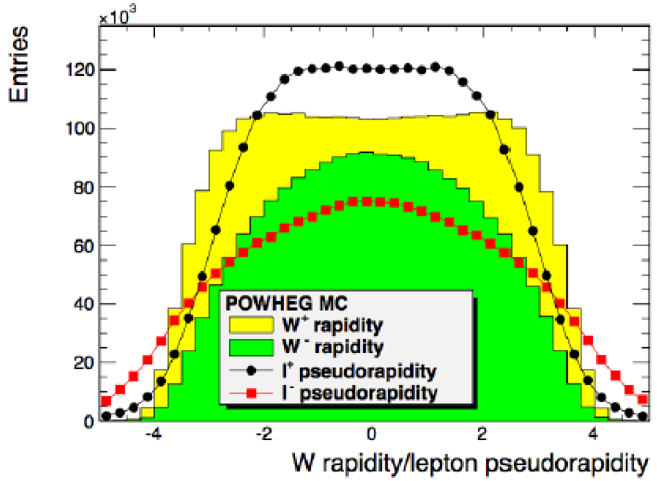


- LHC: dominated by sea quark and gluon production

- Tevatron measurements place stringent constraints on valence PDFs







Impacts of PDFs

- Parton distribution functions are not directly calculable, must be determined using experimental inputs
- Many precision measurements are dominated by the PDF uncertainty

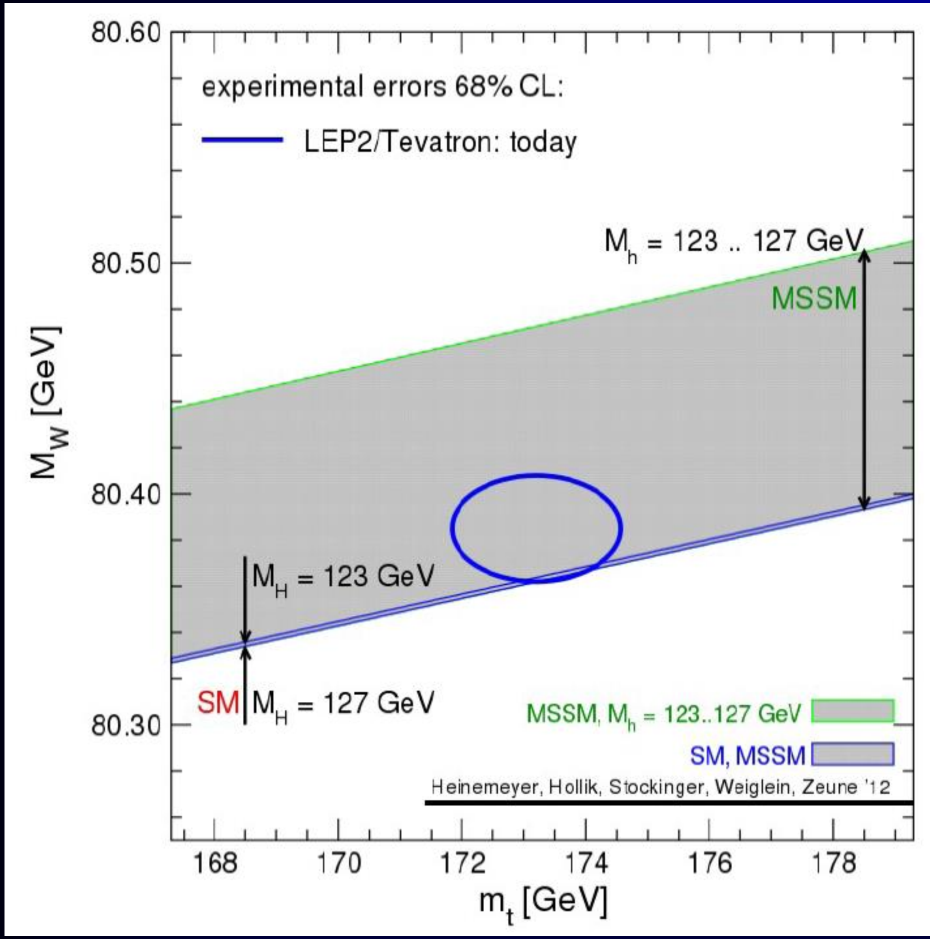
TABLE III. The input data used in the M_W combination. All entries are in units of MeV.

	CDF [8]	CDF [9]	CDF [10]	D0 [12–15]	D0 [16]	CDF [17]	D0 [18]
	(1988–1989)	(1992–1993)	(1994–1995)	(1992–1995)	(2002–2006)	(2002–2007)	(2006–2009)
	4.4 pb^{-1}	18.2 pb^{-1}	84 pb^{-1}	95 pb^{-1}	1.0 fb^{-1}	2.2 fb^{-1}	4.3 fb^{-1}
Mass and width							
M_W	79 910	80 410	80 470	80 483	80 400	80 387	80 367
Γ_W	2 100	2 064	2 096	2 062	2 099	2 094	2 100
M_W uncertainties							
PDF	60	50	15	8	10	10	11
Radiative corrections	10	20	5	12	7	4	7
Γ_W	0.5	1.4	0.3	1.5			
Total	390	181	89	84			
M_W corrections							
$\Delta\Gamma_W$	+1.2	−4.2	+0.6	−4.5	+1.1	+0.3	+1.2
PDF	+20	−25	0	0	0	0	0
Fit method	−3.5	−3.5	−0.1	0	0	0	0
Total	+17.7	−32.7	+0.5	−4.5	+1.1	+0.3	+1.2
M_W corrected	79 927.7	80 377.3	80 470.5	80 478.5	80 401.8	80 387.3	80 368.6

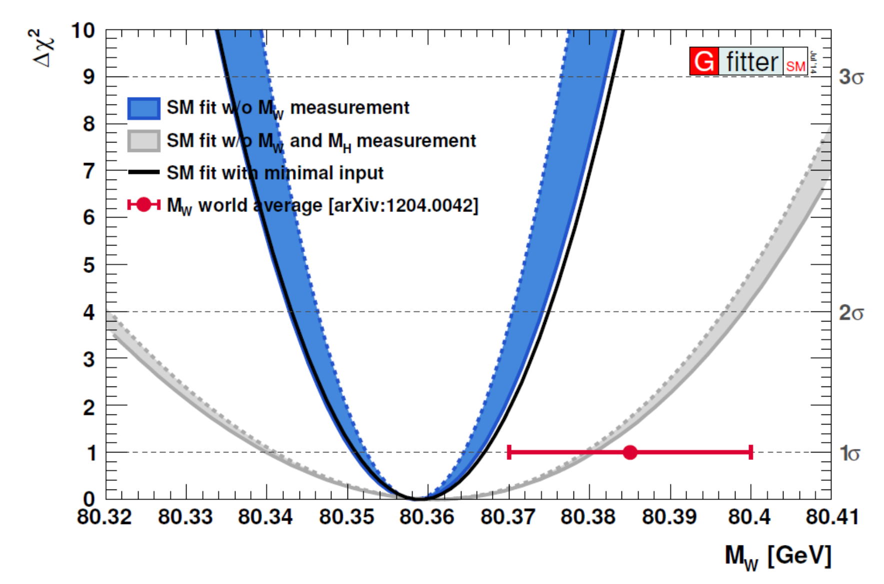
Stat.: 12 13 MeV

Phys. Rev. D **88**, 052018 (2013)

W Boson Mass



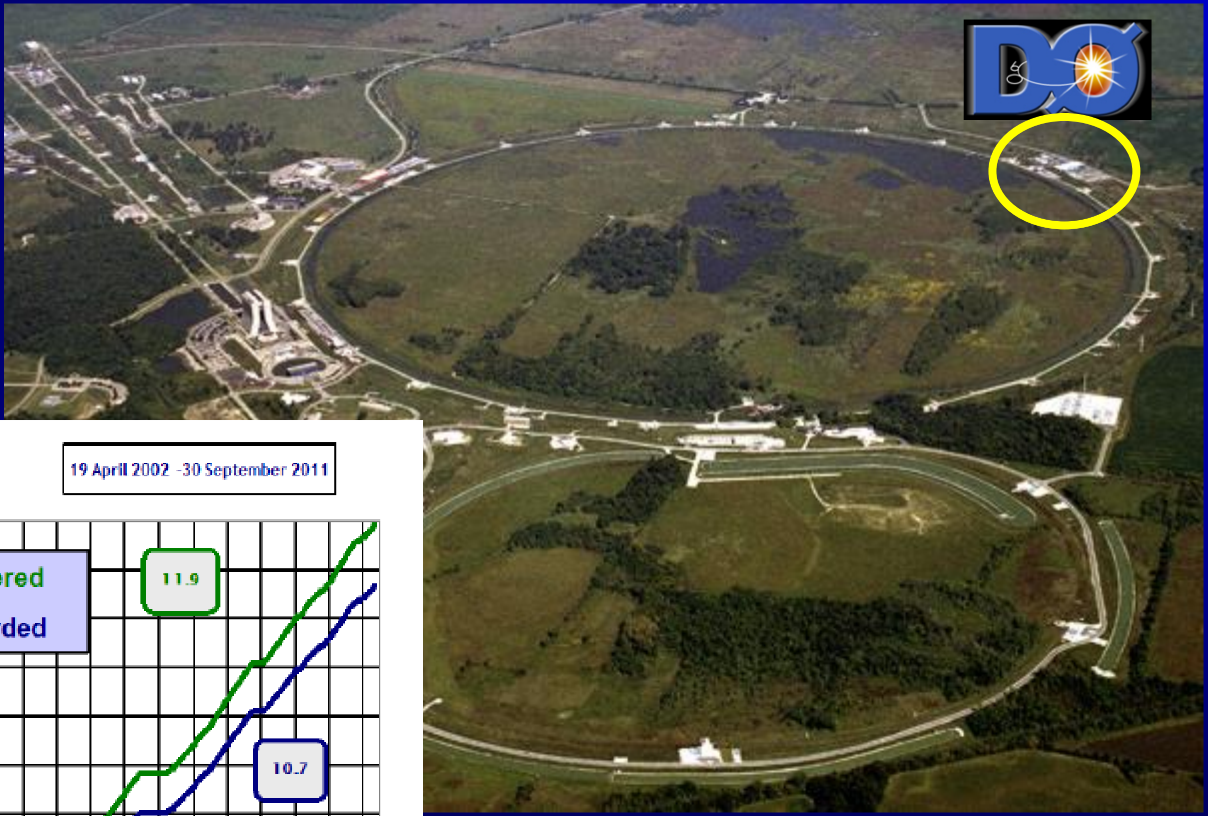
- GFitter collaboration arXiv:1407.3792

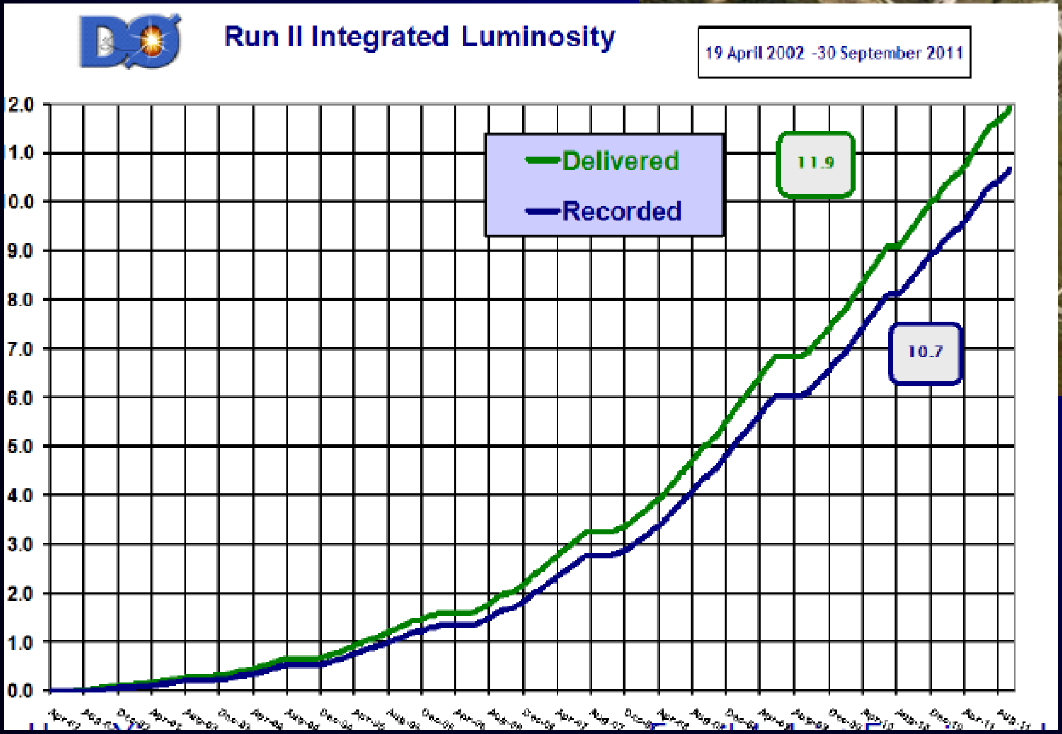


- M_W direct measurement: (80.385 ± 0.015) GeV
- M_W indirect determination: (80.358 ± 0.008) GeV

Our Chapter: DØ

- **Great thanks to Accelerator Division for all the luminosity!!**

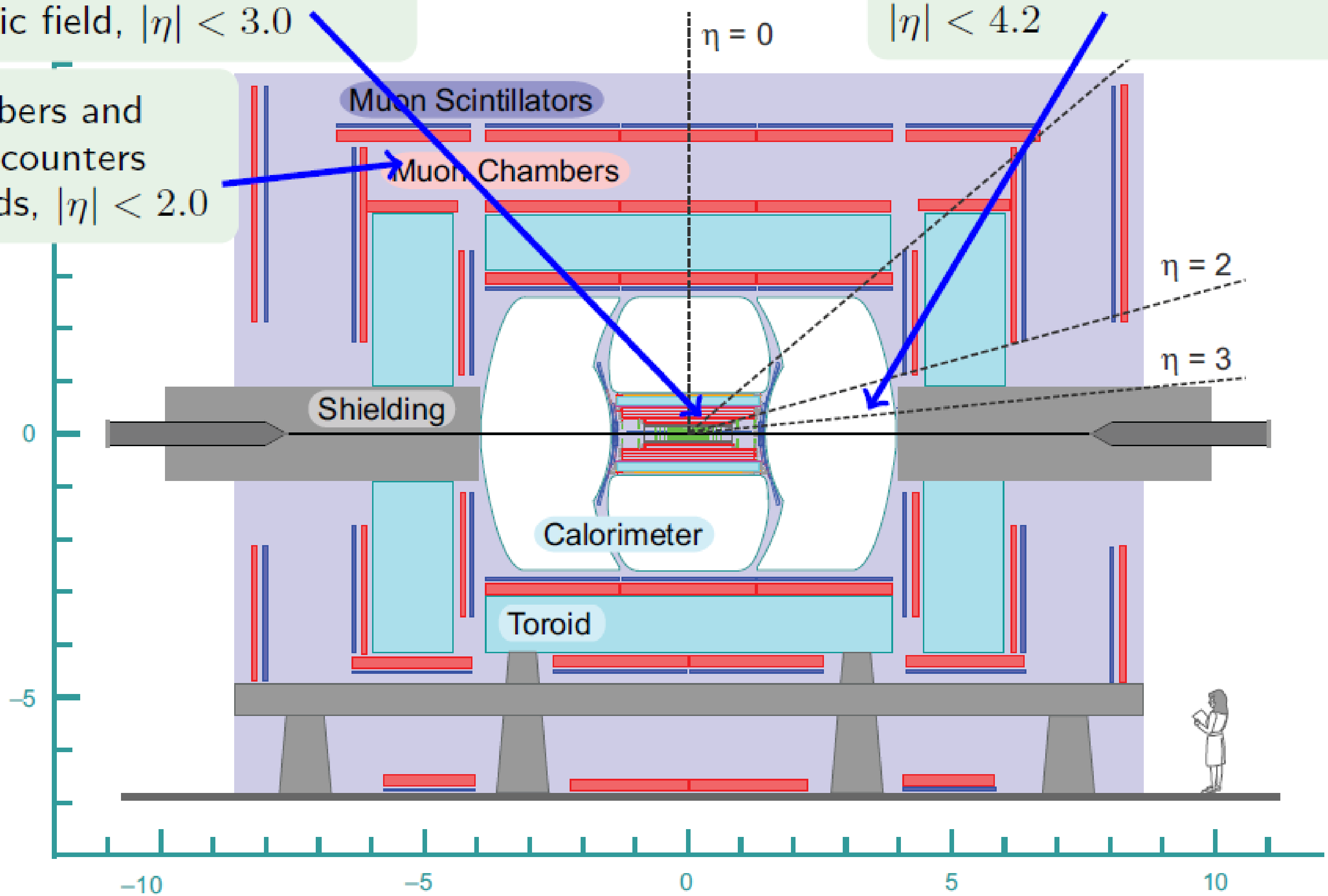




Silicon Microstrip Tracker (SMT)
Central Fiber Tracker (CFT)
2T magnetic field, $|\eta| < 3.0$

Uranium Liquid Argon calorimeters
Central (CC) and Endcap (EC)
$|\eta| < 4.2$

Drift chambers and
scintillator counters
1.8T Toroids, $|\eta| < 2.0$



2014 Inductees

ϕ^*: Birth of a Boson

A: Vectors from birth to death

θ_W: EW Mortality Statistics

ϕ*: Birth of a Boson

FERMILAB-PUB-14-430-E

arXiv:1410.8052v2 [hep-ex] 30 Oct 2014

Measurement of the ϕ^*_η distribution of muon pairs with masses between 30 and 500 GeV in 10.4 fb^{-1} of $p\bar{p}$ collisions

V.M. Abazov,[31] B. Abbott,[67] B.S. Acharya,[25] M. Adams,[46] T. Adams,[44] J.P. Agnew,[41] G.D. Alexeev,[31]
G. Alkhazov,[35] A. Alton[a],[56] A. Askew,[44] S. Atkins,[54] K. Augsten,[7] C. Avila,[5] F. Badaud,[10] L. Bagby,[45]
B. Baldin,[45] D.V. Bandurin,[73] S. Banerjee,[25] E. Barberis,[55] P. Baringer,[53] J.F. Bartlett,[45] U. Bassler,[15]
V. Bazterra,[46] A. Bean,[53] M. Begalli,[2] L. Bellantoni,[45] S.B. Beri,[23] G. Bernardi,[14] R. Bernhard,[19] I. Bertram,[39]
M. Besançon,[15] R. Beuselinck,[40] P.C. Bhat,[45] S. Bhatia,[58] V. Bhatnagar,[23] G. Blazey,[47] S. Blessing,[44] K. Bloom,[59]
A. Boehnlein,[45] D. Boline,[64] E.E. Boos,[33] G. Borissov,[39] M. Borysova[l],[38] A. Brandt,[70] O. Brandt,[20] R. Brock,[57]
A. Bross,[45] D. Brown,[14] X.B. Bu,[45] M. Buehler,[45] V. Buescher,[21] V. Bunichev,[33] S. Burdin[b],[39] C.P. Buszello,[37]
E. Camacho-Pérez,[28] B.C.K. Casey,[45] H. Castilla-Valdez,[28] S. Caughron,[57] S. Chakrabarti,[64] K.M. Chan,[51]
A. Chandra,[72] E. Chapon,[15] G. Chen,[53] S.W. Cho,[27] S. Choi,[27] B. Choudhary,[24] S. Cihangir,[45] D. Claes,[59]
J. Clutter,[53] M. Cooke[k],[45] W.E. Cooper,[45] M. Corcoran,[72] F. Couderc,[15] M.-C. Cousinou,[12] D. Cutts,[69] A. Das,[42]
G. Davies,[40] S.J. de Jong,[29,30] E. De La Cruz-Burelo,[28] F. Déliot,[15] R. Demina,[63] D. Denisov,[45] S.P. Denisov,[34]
S. Desai,[45] C. Deterre[c],[41] K. DeVaughan,[59] H.T. Diehl,[45] M. Diesburg,[45] P.F. Ding,[41] A. Dominguez,[59] A. Dubey,[24]
L.V. Dudko,[33] A. Duperrin,[12] S. Dutt,[23] M. Eads,[47] D. Edmunds,[57] J. Ellison,[43] V.D. Elvira,[45] Y. Enari,[14]
H. Evans,[49] V.N. Evdokimov,[34] A. Fauré,[15] L. Feng,[47] T. Ferbel,[63] F. Fiedler,[21] F. Filthaut,[29,30] W. Fisher,[57]
H.E. Fisk,[45] M. Fortner,[47] H. Fox,[39] S. Fuess,[45] P.H. Garbincius,[45] A. Garcia-Bellido,[63] J.A. García-González,[28]
V. Gavrilov,[32] W. Geng,[12,57] C.E. Gerber,[46] Y. Gershtein,[60] G. Ginther,[45,63] O. Gogota,[38] G. Golovanov,[31]
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S. Grünendahl,[45] M.W. Grünewald,[26] T. Guillemin,[13] G. Gutierrez,[45] P. Gutierrez,[67] J. Haley,[68] L. Han,[4]
K. Harder,[41] A. Harel,[63] J.M. Hauptman,[52] J. Hays,[40] T. Head,[41] T. Hebbeker,[18] D. Hedin,[47] H. Hegab,[68]
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Z. Hubacek,[7,15] V. Hynek,[7] I. Iashvili,[62] Y. Ilchenko,[71] R. Illingworth,[45] A.S. Ito,[45] S. Jabeen[m],[45]
M. Jaffré,[13] A. Jayasinghe,[67] M.S. Jeong,[27] R. Jesik,[40] P. Jiang,[4] K. Johns,[42] E. Johnson,[57] M. Johnson,[45]
A. Jonckheere,[45] P. Jonsson,[40] J. Joshi,[43] A.W. Jung,[45] A. Juste,[36] E. Kajfasz,[12] D. Karmanov,[33] I. Katsanos,[59]
M. Kaur,[23] R. Kehoe,[71] S. Kermiche,[12] N. Khalatyan,[45] A. Khanov,[68] A. Kharchilava,[62] Y.N. Kharzheev,[31]
I. Kiselevich,[32] J.M. Kohli,[23] A.V. Kozelov,[34] J. Kraus,[58] A. Kumar,[62] A. Kupco,[8] T. Kurča,[17] V.A. Kuzmin,[33]
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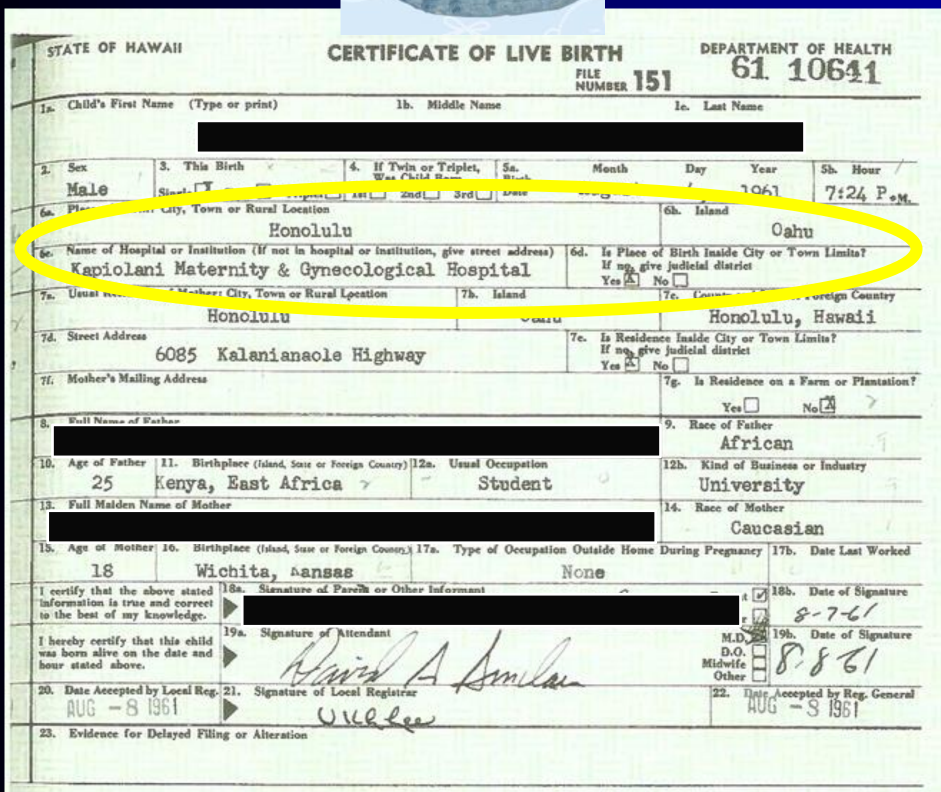
L. Li,[43] Q.Z. Li,[45] X. Li,[41] J.K. Lim,[27] D. Lincoln,[45] J. Linnemann,[57] V.V. Lipaev,[34] R. Lipton,[45] H. Liu,[71]
Y. Liu,[4] A. Lobodenko,[35] M. Lokajicek,[8] R. Lopes de Sa,[45] R. Luna-Garcia[g],[28] A.L. Lyon,[45] A.K.A. Maciel,[1]

ϕ*: Birth of a Boson



STATE OF HAWAII — CERTIFICATE OF LIVE BIRTH — DEPARTMENT OF HEALTH

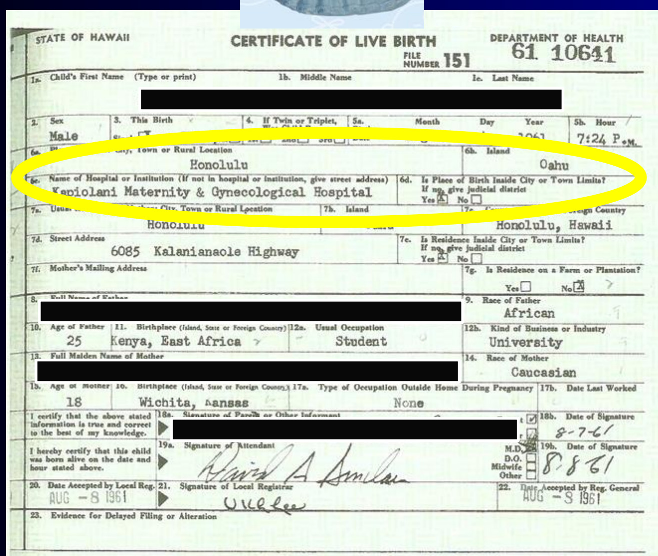
FILE NUMBER 151 — 61 10641

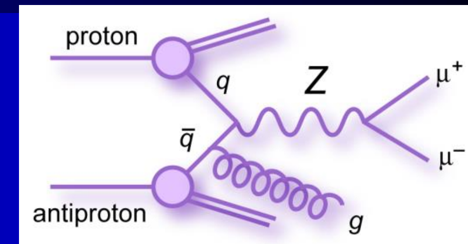
1a. Child's First Name (Type or print)	1b. Middle Name	1c. Last Name
[redacted]		

2. Sex: Male	3. This Birth: Single	4. If Twin or Triplet, Was Child Born 1st / 2nd / 3rd	5a. Birth Date: Month / Day / Year 1961	5b. Hour: 7:24 P.M.

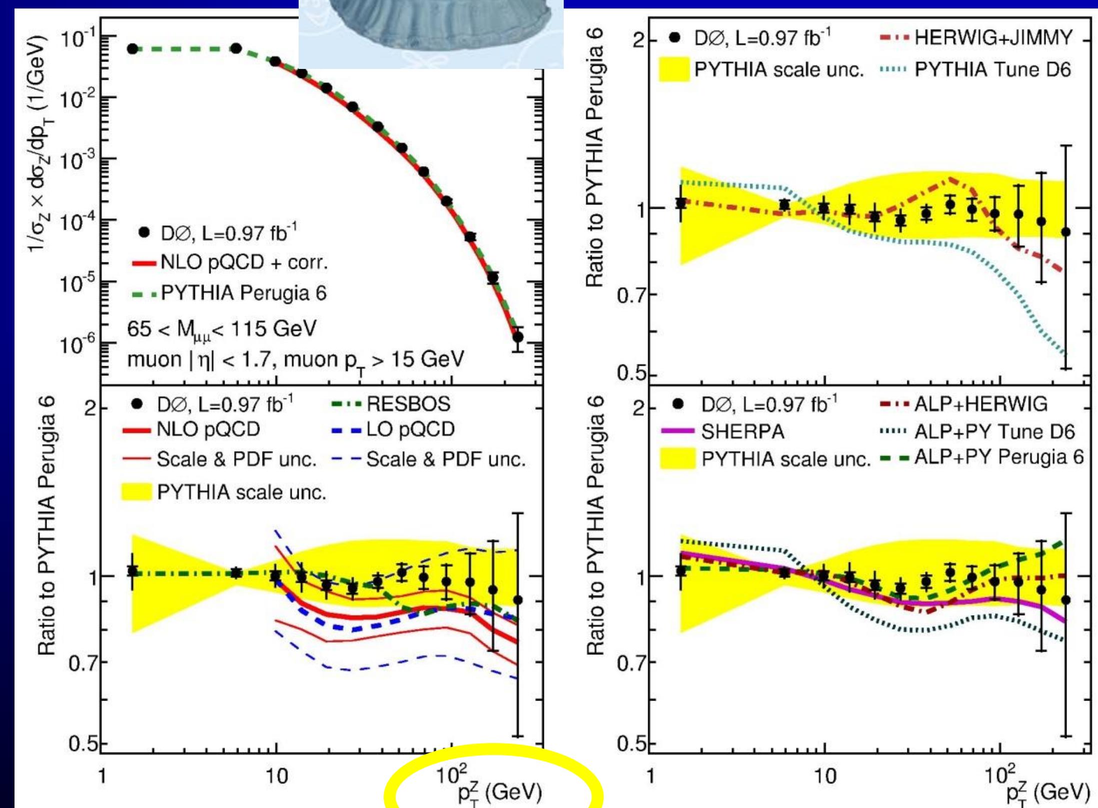
6a. Place of Birth: City, Town or Rural Location: Honolulu	6b. Island: Oahu
6c. Name of Hospital or Institution (If not in hospital or institution, give street address): Kapiolani Maternity & Gynecological Hospital	6d. Is Place of Birth Inside City or Town Limits? If no, give judicial district. Yes [X] No [ ]
7a. Usual Residence of Mother: City, Town or Rural Location: Honolulu — 7b. Island: Oahu	7c. County and State or Foreign Country: Honolulu, Hawaii
7d. Street Address: 6085 Kalanianaole Highway	7e. Is Residence Inside City or Town Limits? If no, give judicial district. Yes [X] No [ ]
7f. Mother's Mailing Address	7g. Is Residence on a Farm or Plantation? Yes [ ] No [X]
8. Full Name of Father: [redacted]	9. Race of Father: African
10. Age of Father: 25 — 11. Birthplace (Island, State or Foreign Country): Kenya, East Africa — 12a. Usual Occupation: Student	12b. Kind of Business or Industry: University
13. Full Maiden Name of Mother: [redacted]	14. Race of Mother: Caucasian
15. Age of Mother: 18 — 16. Birthplace (Island, State or Foreign Country): Wichita, Kansas — 17a. Type of Occupation Outside Home During Pregnancy: None	17b. Date Last Worked
I certify that the above stated information is true and correct to the best of my knowledge. 18a. Signature of Parent or Other Informant: [redacted]	18b. Date of Signature: 8-7-61
I hereby certify that this child was born alive on the date and hour stated above. 19a. Signature of Attendant: David A Sinclair — M.D. [X] D.O. [ ] Midwife [ ] Other [ ]	19b. Date of Signature: 8-8-61
20. Date Accepted by Local Reg.: AUG -8 1961 — 21. Signature of Local Registrar: UKLee	22. Date Accepted by Reg. General: AUG -8 1961
23. Evidence for Delayed Filing or Alteration	

ϕ^*: Birth of a Boson



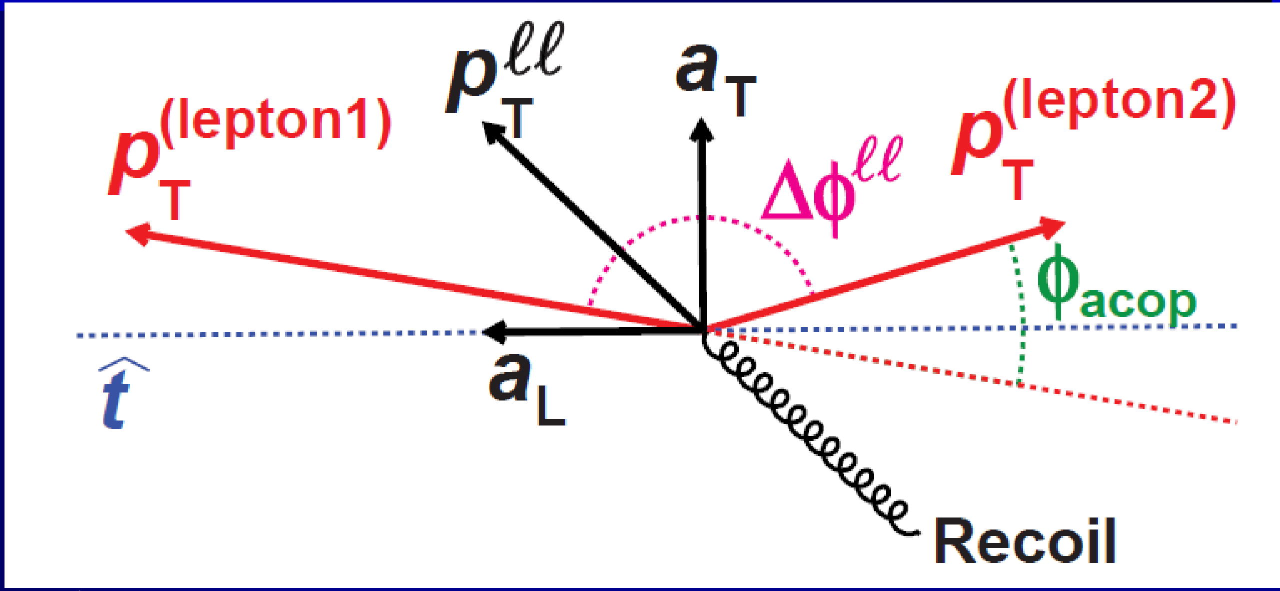


- PLB 693, 522 (2010)



ϕ^*: Definition

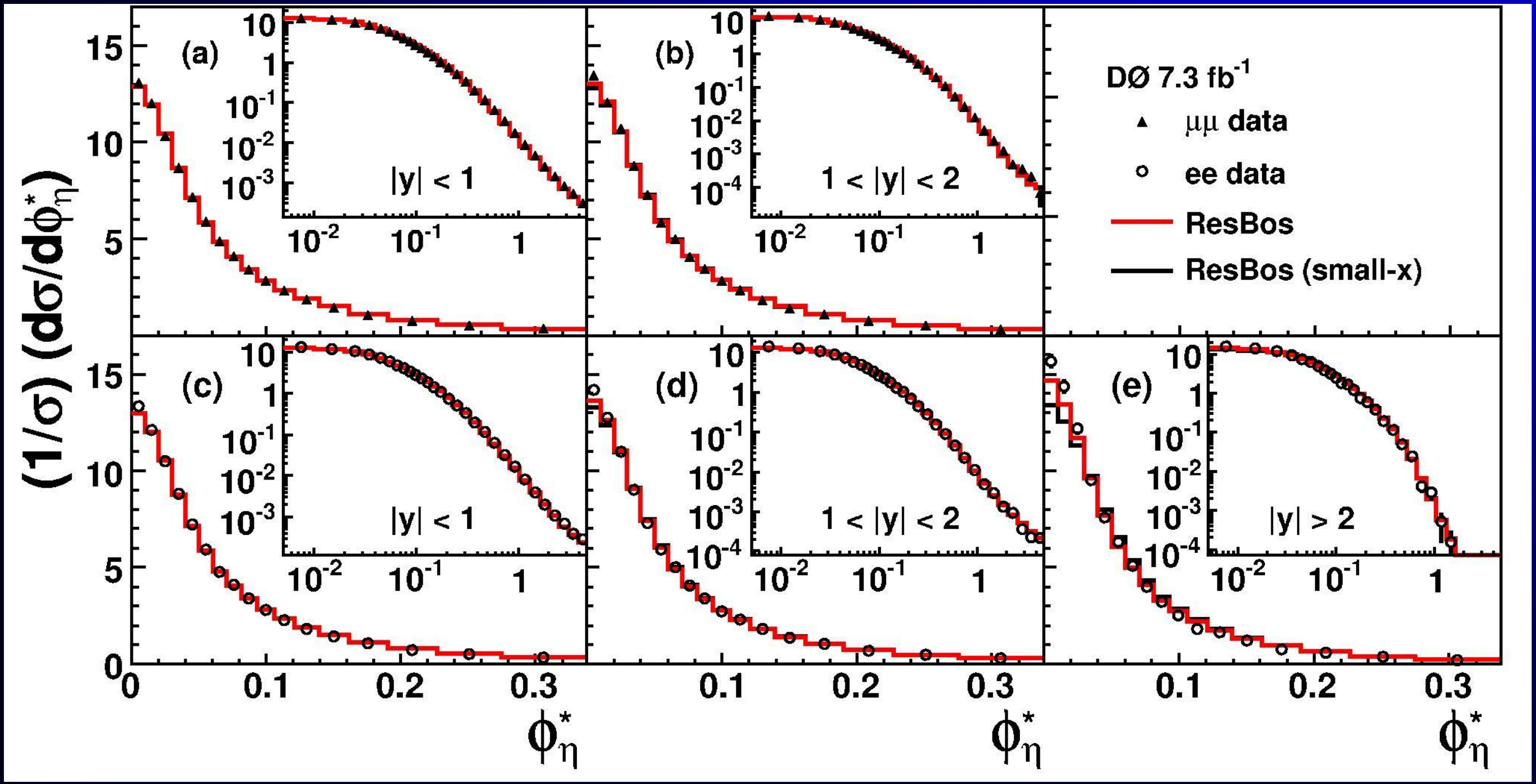
- Eur. Phys. J. C71 1600(2011)



- $\boldsymbol{\phi^* = \tan(\phi_{acop}/2)\sin\theta^*}$
  - $\phi_{acop} = \pi - \Delta\phi^{ll}$
  - $\cos\theta^* = \tanh((\eta_- - \eta_+)/2)$ [Collins-Soper angle]
- **ϕ^* probes same physics as p_T^{ll}, $\phi^* \sim a_T/M_{ll}$**
- **ϕ^* less sensitive to detector resolution and efficiency**
  - Uses angles only (mrad precision with < 1% resolution vs. few % resolution on *p*, *E*)

ϕ*: Peak Region

- First measured by D0 with 7.3 fb^{-1}
  - PRL 106, 122001 (2011)



ϕ^*: Peak Region

- **First measured by D0 with 7.3 fb^{-1}**
  - PRL 106, 122001 (2011)

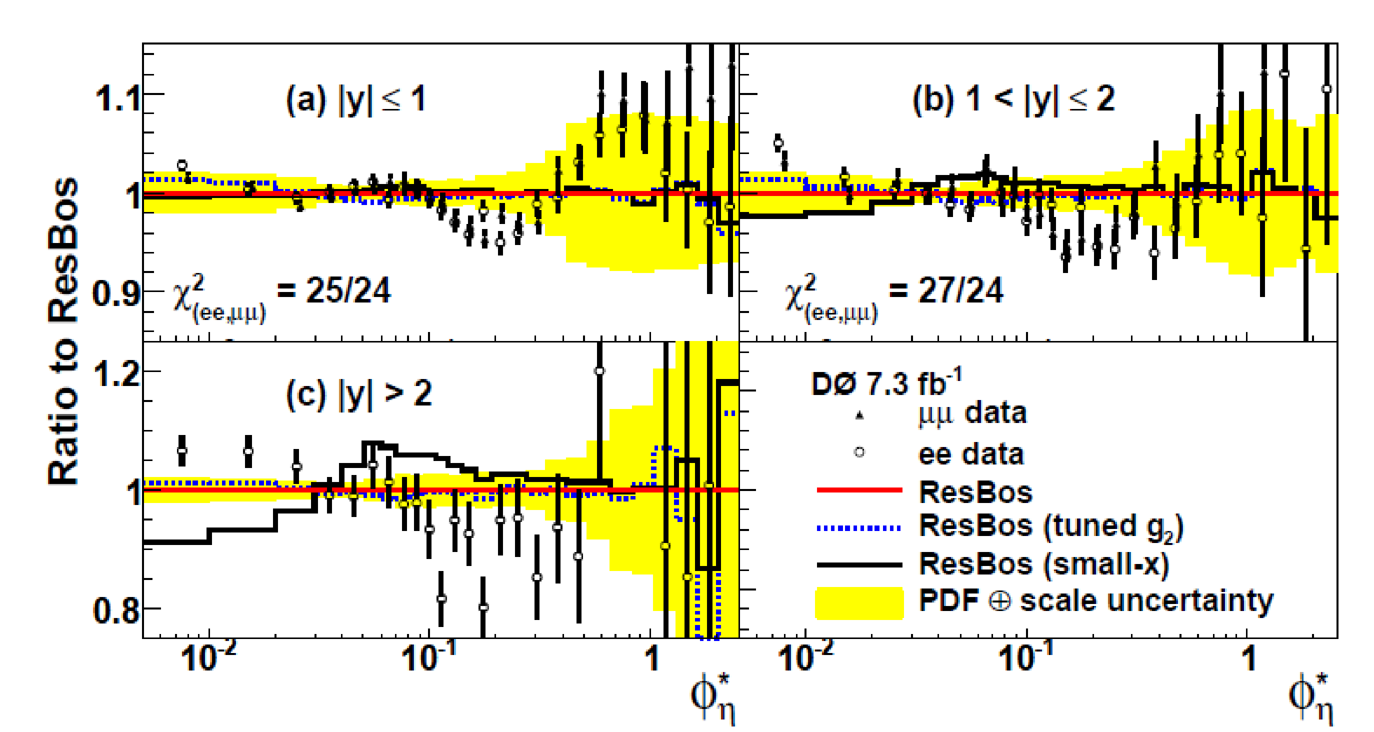
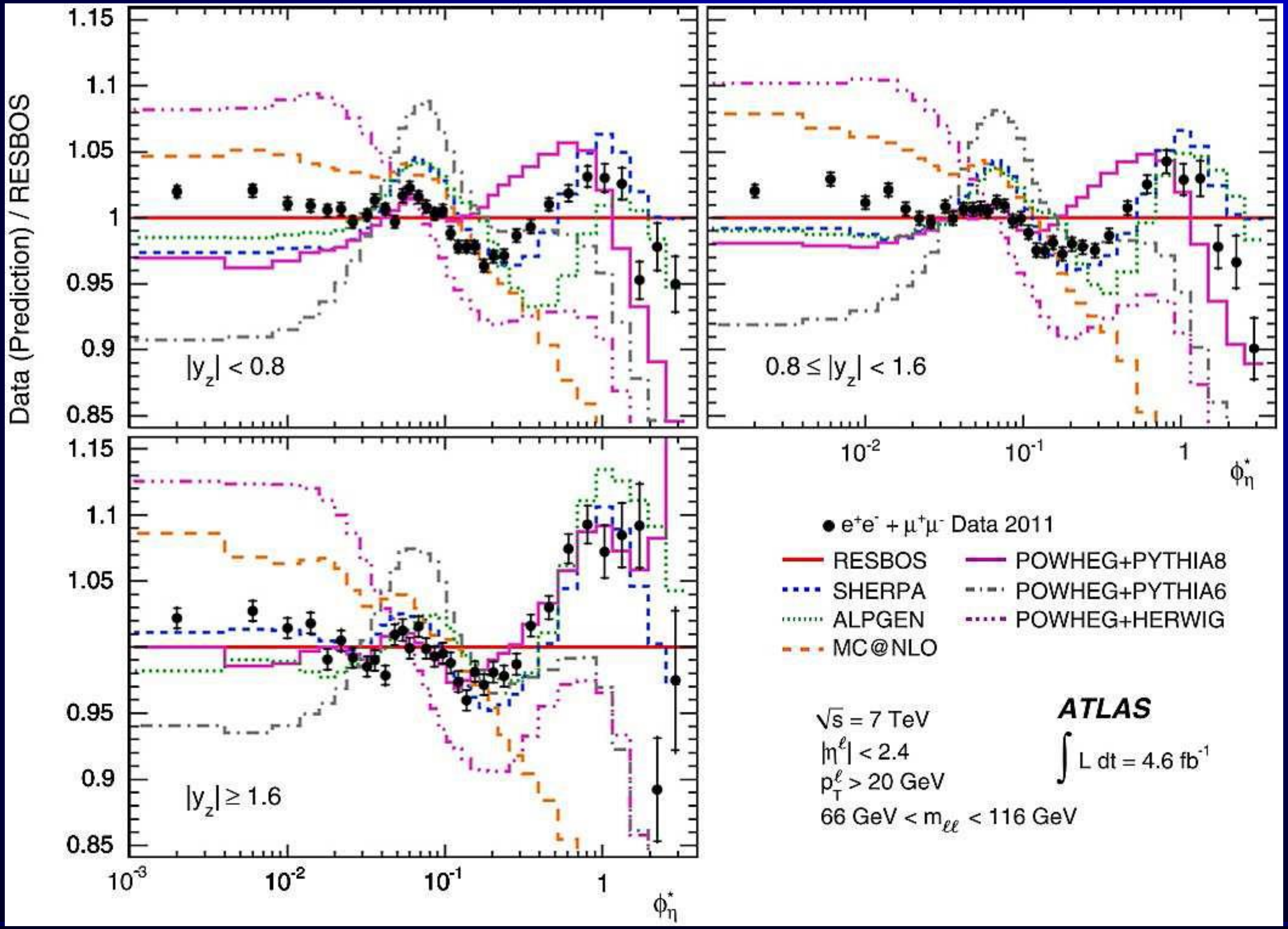


Figure: $M_{\mu\mu} \in (70, 110)$

- **Data used to improve ResBos and make predictions for LHC**

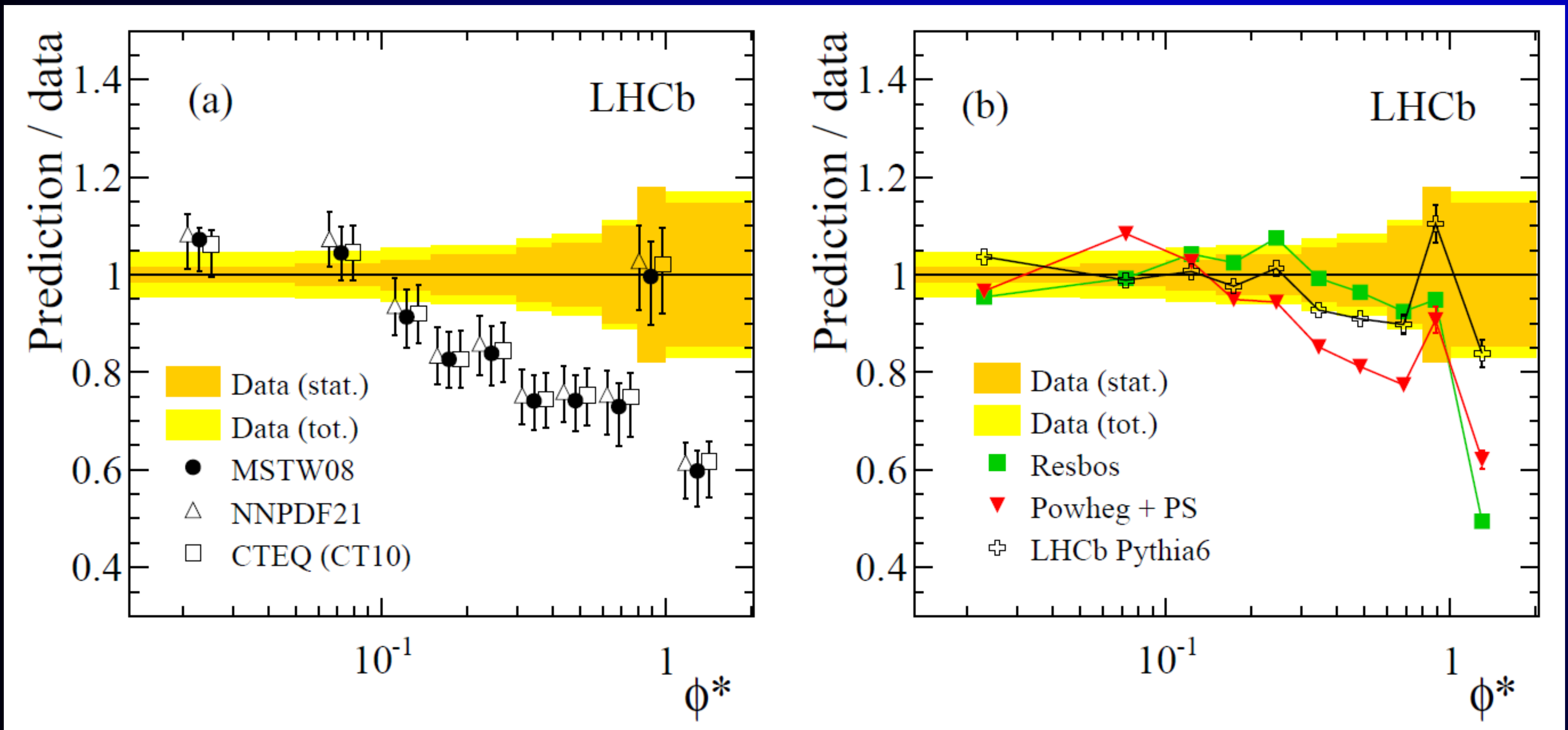
ϕ*: Peak Region

- **ATLAS**
  - Phys. Lett. B 720, 32(2013)



ϕ^*: Peak Region

- **LHCb**
  - JHEP 1302, 106(2013)



ϕ^*: Off-peak Regions

Low Mass: $M_{\mu\mu} \in (30, 60)$ GeV

- **More sensitive to small-*x* effects**
  - Statistically more powerful than forward rapidity region (|y| > 2) in dielectron channel in the published peak region analysis
  - $x_{1,2} = M/\sqrt{s}e^{\pm y}$

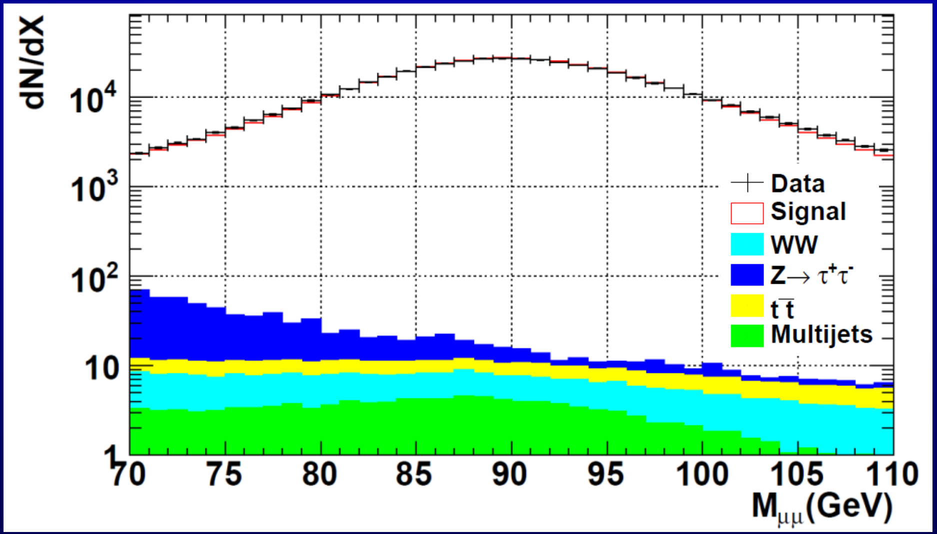
High Mass: $M_{\mu\mu} \in (160, 300) \cup (300, 500)$ GeV

- **Constrain initial state QCD radiation uncertainties for high mass final states**
  - e.g. top quark physics

ϕ^*: Event Selection

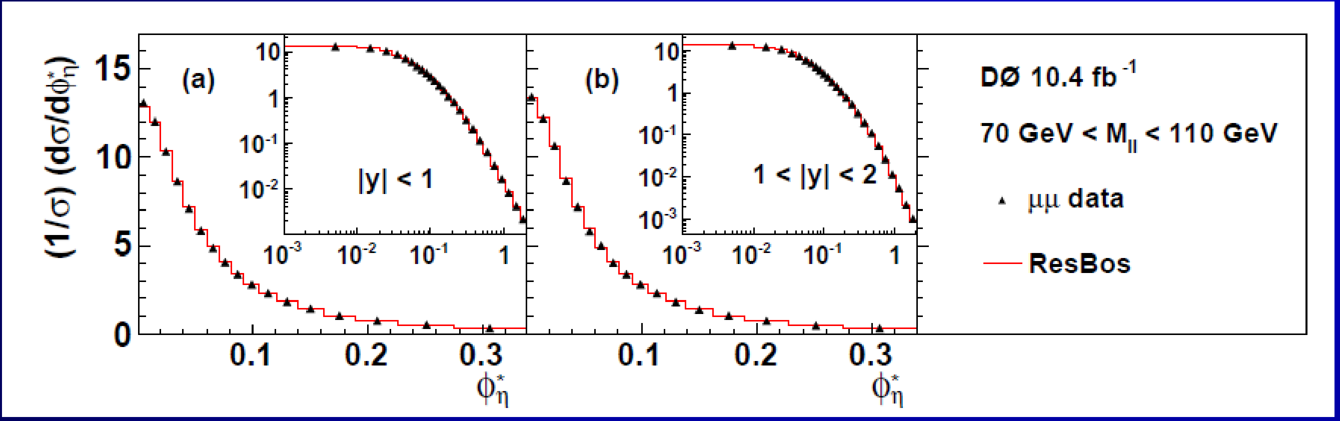
- **Select events with two good quality muons (isolation, track segments, vertex)**
  - Tighter quality cuts for low mass region to control backgrounds

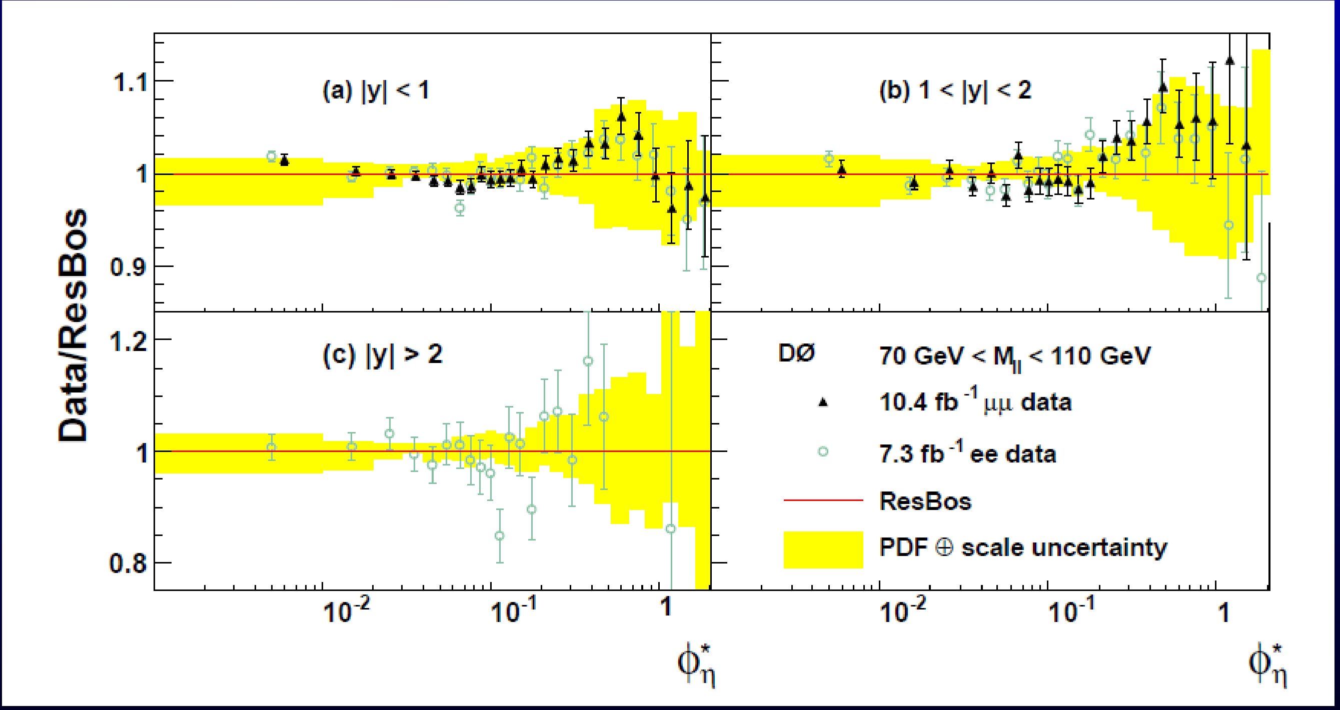
- **Peak region**
  - $M_{\mu\mu} \in (70,110)$ GeV:
  - 645k events with 99.84% signal
- **Low mass region**
  - $M_{\mu\mu} \in (30,60)$ GeV
  - 74k events with 89.5% signal
- **High mass region**
  - $M_{\mu\mu} \in (160,300)$ GeV: 1.7k events with 72.8% signal
  - $M_{\mu\mu} \in (300,500)$ GeV: 0.2k events with 56.6% signal



ϕ^*: Peak Region Results

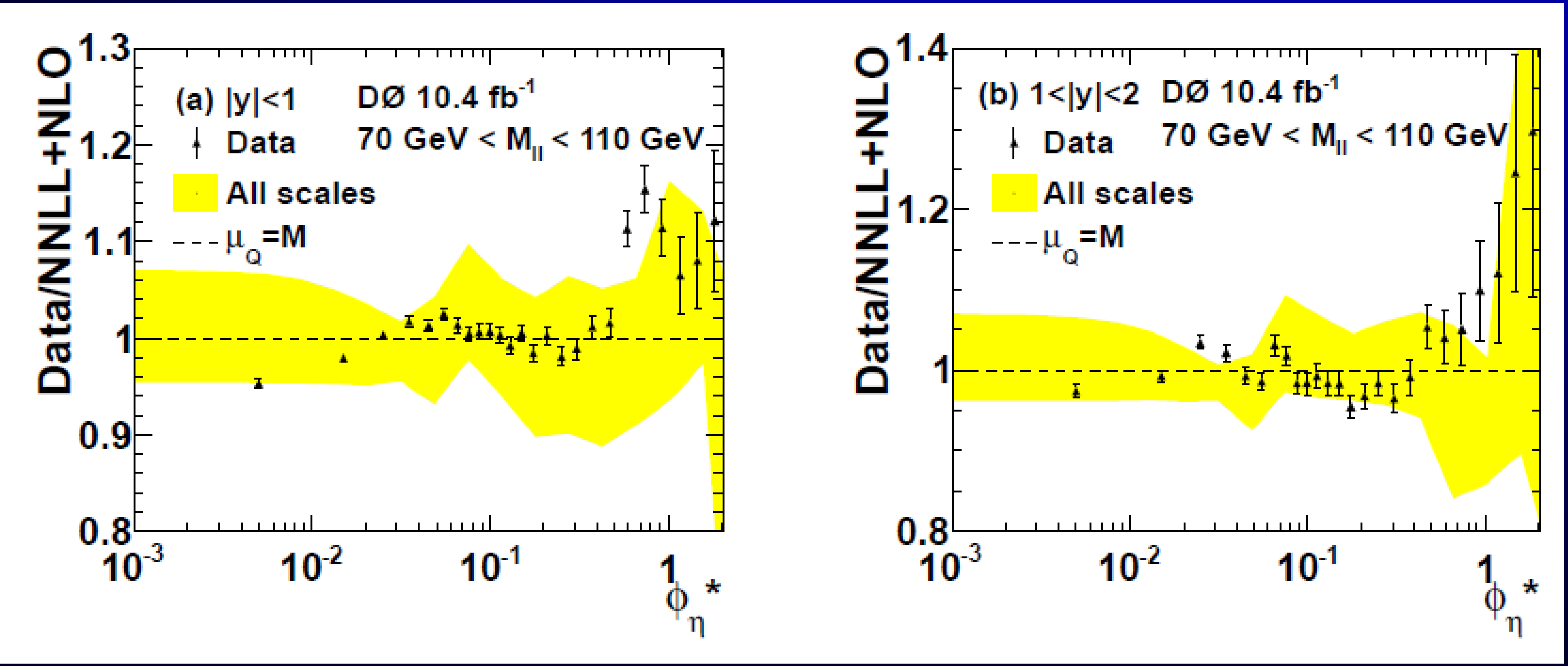
- **Comparison with the ResBos prediction**
  - M. Guzzi *et al. arXiv: 1309.1393*





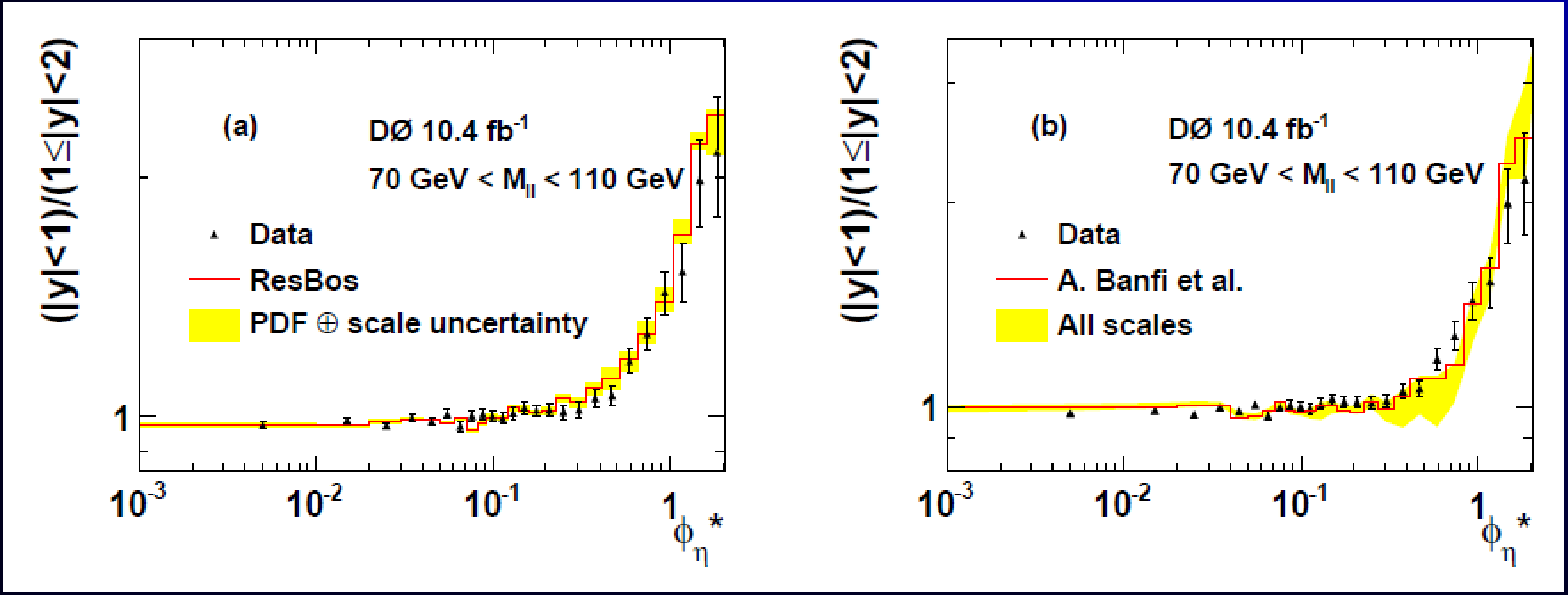
ϕ*: Peak Region Results

- **Comparison with a NLO+NNLL QCD prediction**
  - A. Banfi *et al*. JHEP01 (2012) 044

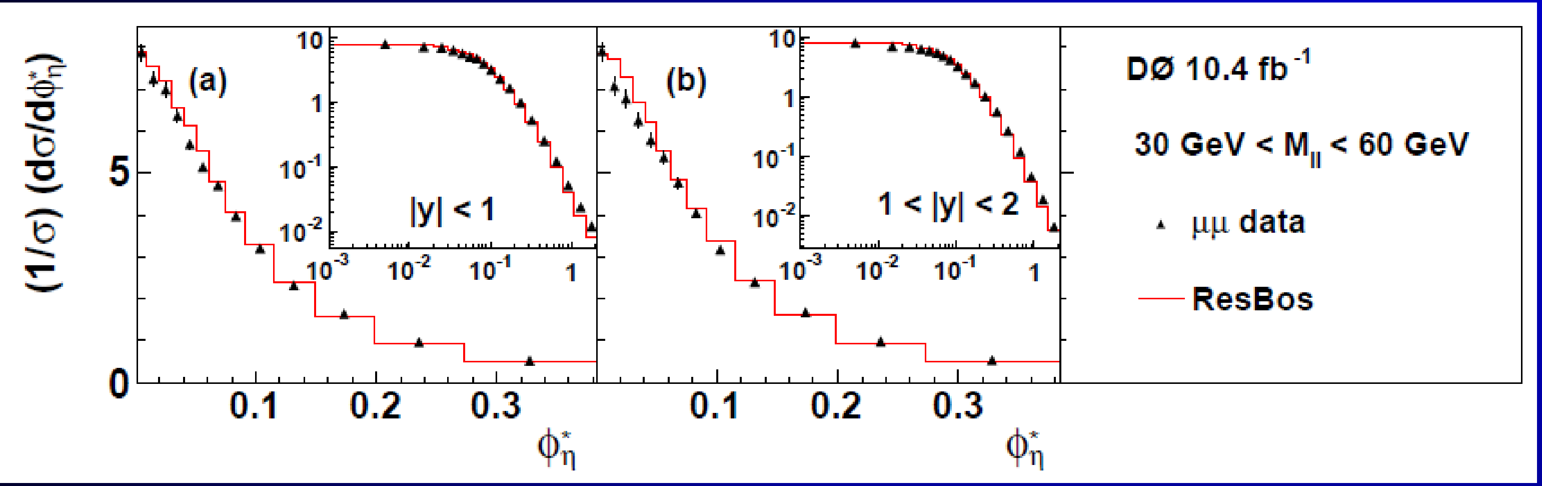


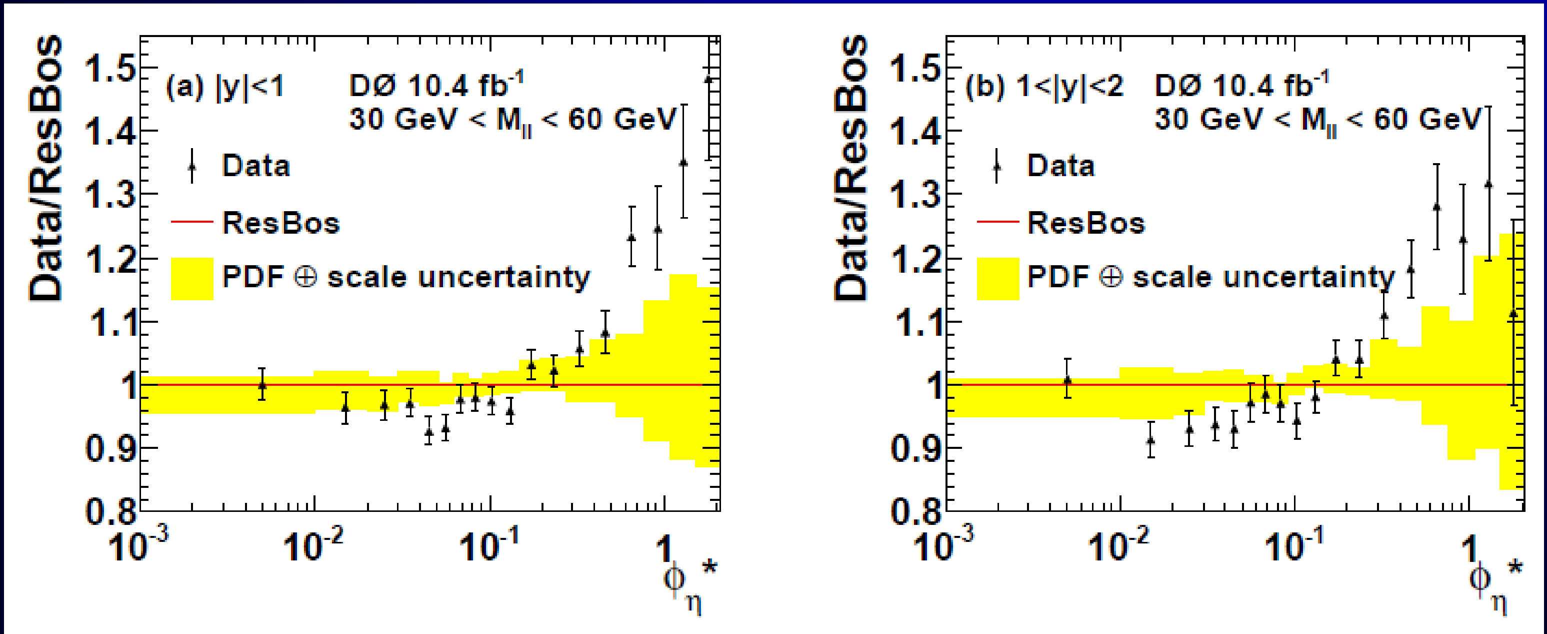
ϕ*: Peak Region Results

- **Ratio of $(1/\sigma)(d\sigma/d\phi^*)$ in rapidity bins**
  - The ratio $(1/\sigma)(d\sigma/d\phi^*)$ in the central rapidity region to that in the forward rapidity region can reduce the uncertainty band from QCD scales to the percent level due to cancellations. It suggests the possibility of a new variable that is less sensitive to theoretical uncertainty.

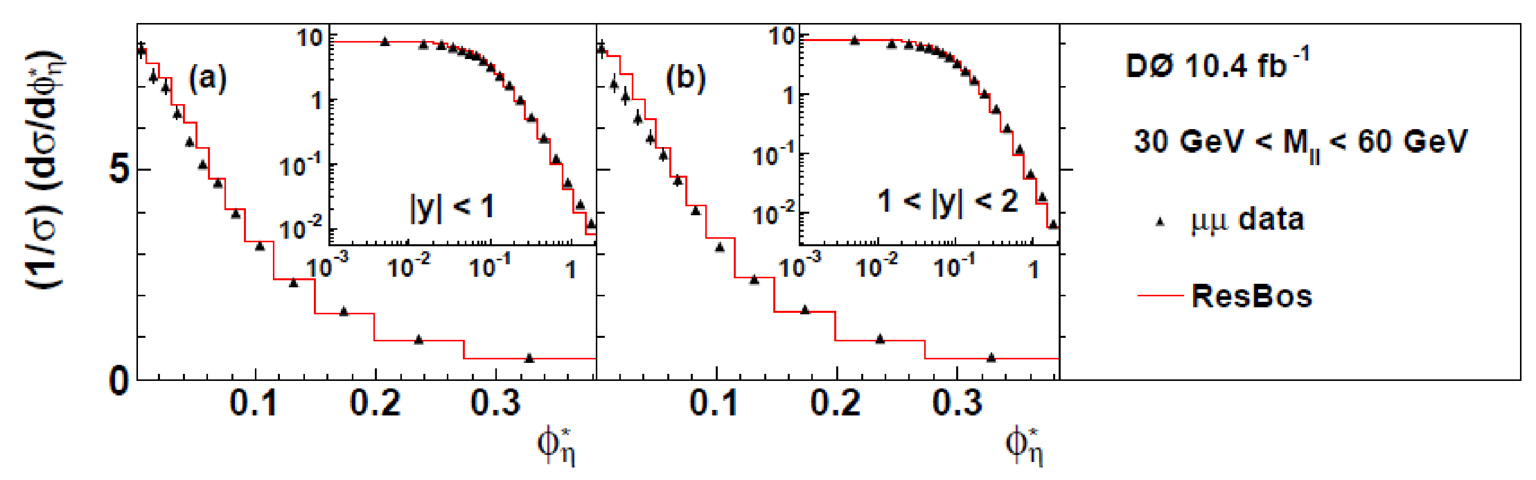


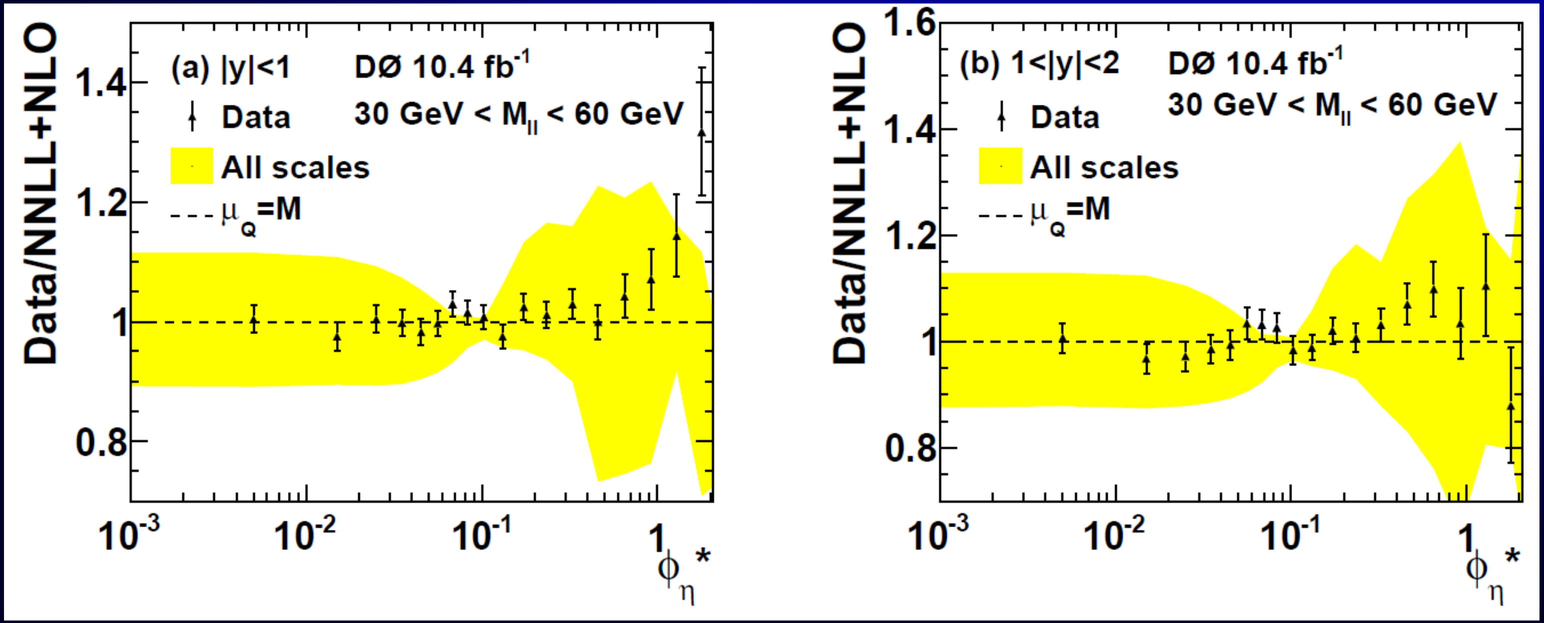
ϕ*: Low Mass Region Results



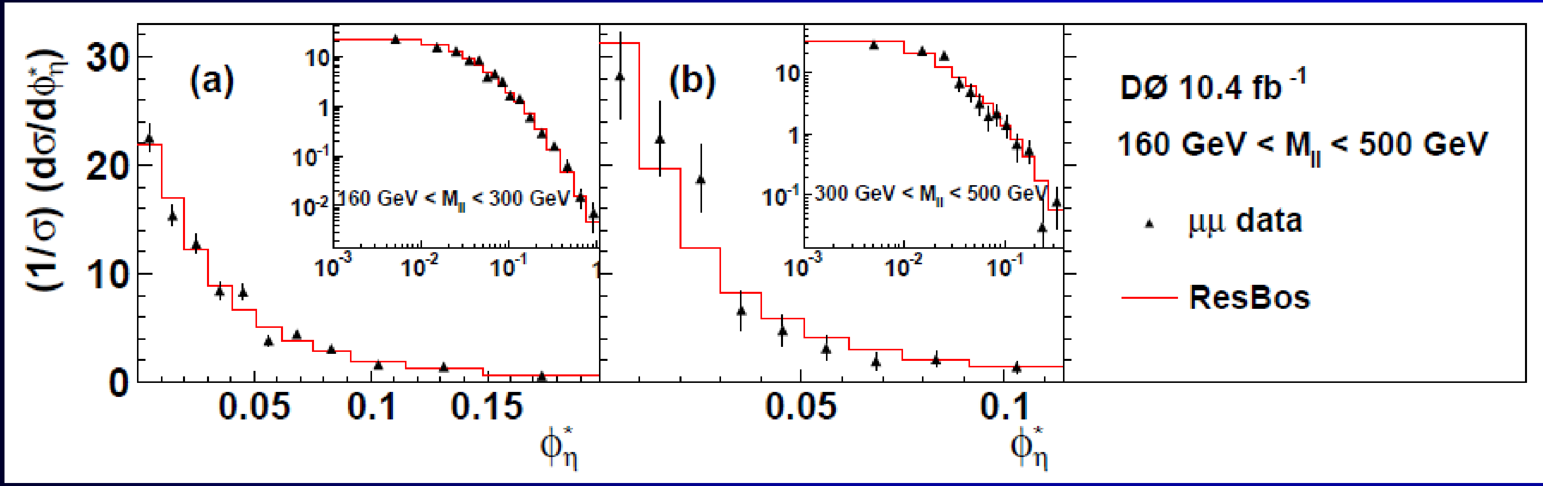


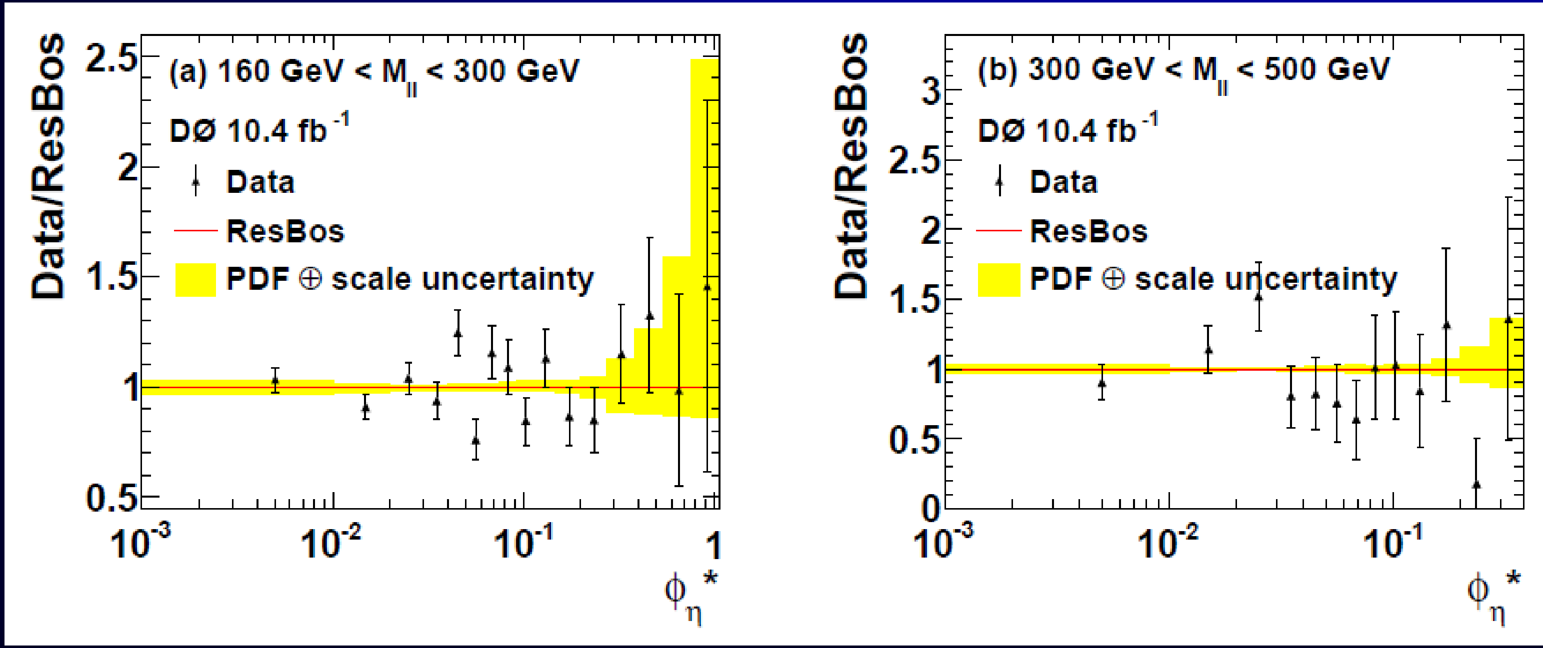
ϕ^*: Low Mass Region Results





ϕ^*: High Mass Region Results





ϕ^*: Summary

- **The transverse momentum has been determined with unprecedented precision in the peak region (645k events)**
  - In excellent agreement with ResBos

- **First ever low-mass region results (74k events)**
  - Helps constrain small-x effects
  - Discrepancy with ResBos at high ϕ^*

- **First ever high-mass region results (2k events)**
  - For constraining QCD ISR in high mass final states
  - No detailed comparison can be made due to limited statistics.

  - A NLO+NNLL QCD prediction is in agreement with data at all mass ranges within assigned theoretical uncertainty.

A: Vectors from Birth to Death

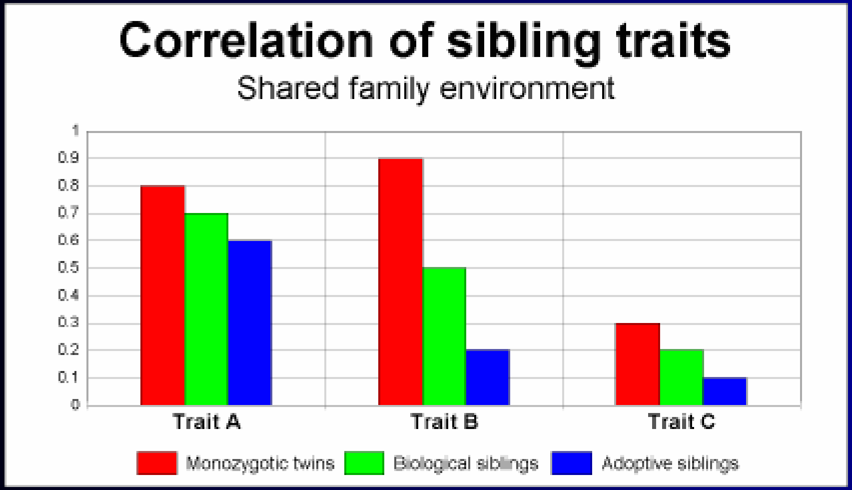
FERMILAB-PUB-13-567-E

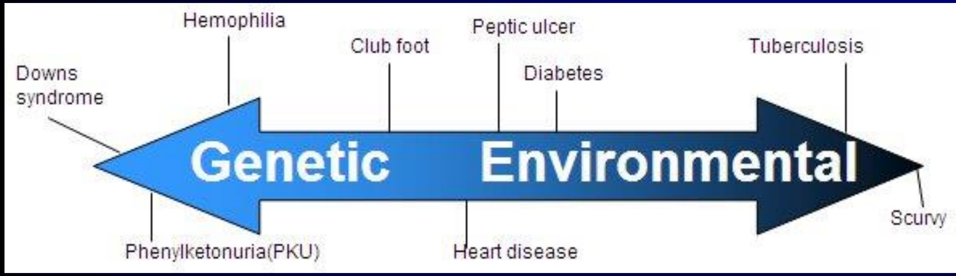
Measurement of the W Boson Production Charge Asymmetry in $p\bar{p} \to W + X \to e\nu + X$ Events at $\sqrt{s} = 1.96$ TeV

V.M. Abazov,[31] B. Abbott,[66] B.S. Acharya,[25] M. Adams,[45] T. Adams,[43] J.P. Agnew,[40] G.D. Alexeev,[31] G. Alkhazov,[35] A. Alton[a],[55] A. Askew,[43] S. Atkins,[53] K. Augsten,[7] C. Avila,[5] F. Badaud,[10] L. Bagby,[44] B. Baldin,[44] D.V. Bandurin,[72] S. Banerjee,[25] E. Barberis,[54] P. Baringer,[52] J.F. Bartlett,[44] U. Bassler,[15] V. Bazterra,[45] A. Bean,[52] M. Begalli,[2] L. Bellantoni,[44] S.B. Beri,[23] G. Bernardi,[14] R. Bernhard,[19] I. Bertram,[38] M. Besançon,[15] R. Beuselinck,[39] P.C. Bhat,[44] S. Bhatia,[57] V. Bhatnagar,[23] G. Blazey,[46] S. Blessing,[43] K. Bloom,[58] A. Boehnlein,[44] D. Boline,[63] E.E. Boos,[33] G. Borissov,[38] A. Brandt,[69] O. Brandt,[20] R. Brock,[56] A. Bross,[44] D. Brown,[14] X.B. Bu,[44] M. Buehler,[44] V. Buescher,[21] V. Bunichev,[33] S. Burdin[b],[38] C.P. Buszello,[37] E. Camacho-Pérez,[28] B.C.K. Casey,[44] H. Castilla-Valdez,[28] S. Caughron,[56] S. Chakrabarti,[63] K.M. Chan,[50] A. Chandra,[71] E. Chapon,[15] G. Chen,[52] S.W. Cho,[27] S. Choi,[27] B. Choudhary,[24] S. Cihangir,[44] D. Claes,[58] J. Clutter,[52] M. Cooke[k],[44] W.E. Cooper,[44] M. Corcoran,[71] F. Couderc,[15] M.-C. Cousinou,[12] D. Cutts,[68] A. Das,[41] G. Davies,[39] S.J. de Jong,[29,30] E. De La Cruz-Burelo,[28] F. Déliot,[15] R. Demina,[62] D. Denisov,[44] S.P. Denisov,[34] S. Desai,[44] C. Deterre[c],[20] K. DeVaughan,[58] H.T. Diehl,[44] M. Diesburg,[44] P.F. Ding,[40] A. Dominguez,[58] A. Dubey,[24] L.V. Dudko,[33] A. Duperrin,[12] S. Dutt,[23] M. Eads,[46] D. Edmunds,[56] J. Ellison,[42] V.D. Elvira,[44] Y. Enari,[14] H. Evans,[48] V.N. Evdokimov,[34] L. Feng,[46] T. Ferbel,[62] F. Fiedler,[21] F. Filthaut,[29,30] W. Fisher,[56] H.E. Fisk,[44] M. Fortner,[46] H. Fox,[38] S. Fuess,[44] P.H. Garbincius,[44] A. Garcia-Bellido,[62] J.A. García-González,[28] V. Gavrilov,[32] W. Geng,[12,56] C.E. Gerber,[45] Y. Gershtein,[59] G. Ginther,[44,62] G. Golovanov,[31] P.D. Grannis,[63] S. Greder,[16] H. Greenlee,[44] G. Grenier,[17] Ph. Gris,[10] J.-F. Grivaz,[13] A. Grohsjean[c],[15] S. Grünendahl,[44] M.W. Grünewald,[26] T. Guillemin,[13] G. Gutierrez,[44] P. Gutierrez,[66] J. Haley,[67] L. Han,[4] K. Harder,[40] A. Harel,[62] J.M. Hauptman,[51] J. Hays,[39] T. Head,[40] T. Hebbeker,[18] D. Hedin,[46] H. Hegab,[67] A.P. Heinson,[42] U. Heintz,[68] C. Hensel,[20] I. Heredia-De La Cruz[d],[28] K. Herner,[44] G. Hesketh[f],[40] M.D. Hildreth,[50] R. Hirosky,[72] T. Hoang,[43] J.D. Hobbs,[63] B. Hoeneisen,[9] J. Hogan,[71] M. Hohlfeld,[21] J.L. Holzbauer,[57] I. Howley,[69] Z. Hubacek,[7,15] V. Hynek,[7] I. Iashvili,[61] Y. Ilchenko,[70] R. Illingworth,[44] A.S. Ito,[44] S. Jabeen,[68] M. Jaffré,[13] A. Jayasinghe,[66] M.S. Jeong,[27] R. Jesik,[39] P. Jiang,[4] K. Johns,[41] E. Johnson,[56] M. Johnson,[44] A. Jonckheere,[44] P. Jonsson,[39] J. Joshi,[42] A.W. Jung,[44] A. Juste,[36] E. Kajfasz,[12] D. Karmanov,[33] I. Katsanos,[58] R. Kehoe,[70] S. Kermiche,[12] N. Khalatyan,[44] A. Khanov,[67] A. Kharchilava,[61] Y.N. Kharzheev,[31] I. Kiselevich,[32] J.M. Kohli,[23] A.V. Kozelov,[34] J. Kraus,[57] A. Kumar,[61] A. Kupco,[8] T. Kurča,[17] V.A. Kuzmin,[33] S. Lammers,[48] P. Lebrun,[17] H.S. Lee,[27] S.W. Lee,[51] W.M. Lee,[44] X. Lei,[41] J. Lellouch,[14] D. Li,[14] H. Li,[72] L. Li,[42] Q.Z. Li,[44] J.K. Lim,[27] D. Lincoln,[44] J. Linnemann,[56] V.V. Lipaev,[34] R. Lipton,[44] H. Liu,[70] Y. Liu,[4] A. Lobodenko,[35] M. Lokajicek,[8] R. Lopes de Sa,[63] R. Luna-Garcia[g],[28] A.L. Lyon,[44] A.K.A. Maciel,[1] R. Madar,[19] R. Magaña-Villalba,[28] S. Malik,[58] V.L. Malyshev,[31] J. Mansour,[20] J. Martínez-Ortega,[28] R. McCarthy,[63] C.L. McGivern,[40] M.M. Meijer,[29,30] A. Melnitchouk,[44] D. Menezes,[46] P.G. Mercadante,[3] M. Merkin,[33] A. Meyer,[18] J. Meyer[i],[20] F. Miconi,[16] N.K. Mondal,[25] M. Mulhearn,[72] E. Nagy,[12] M. Narain,[68] R. Nayyar,[41] H.A. Neal,[55] J.P. Negret,[5] P. Neustroev,[35] H.T. Nguyen,[72] T. Nunnemann,[22] J. Orduna,[71] N. Osman,[12] J. Osta,[50] A. Pal,[69] N. Parashar,[49] V. Parihar,[68] S.K. Park,[27] R. Partridge[e],[68] N. Parua,[48] A. Patwa[j],[64] B. Penning,[44] M. Perfilov,[33] Y. Peters,[40] K. Petridis,[40] G. Petrillo,[62] P. Pétroff,[13]

A: Vectors from Birth to Death

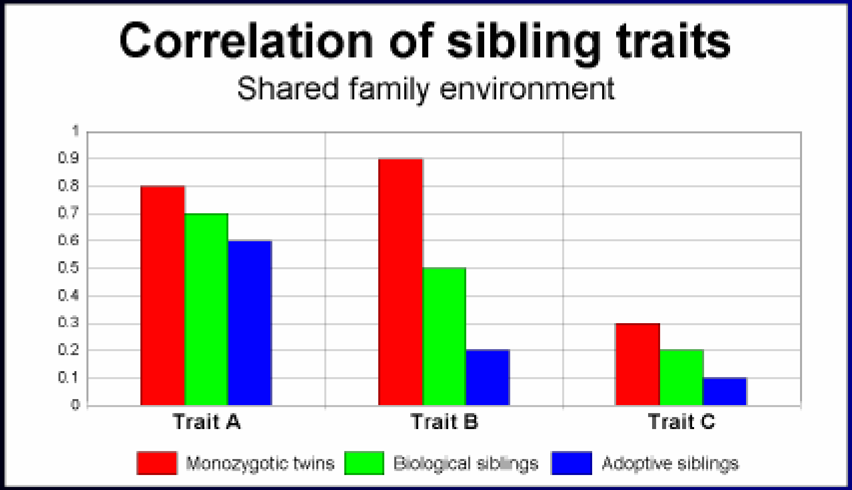
- **Nature vs. Nurture**

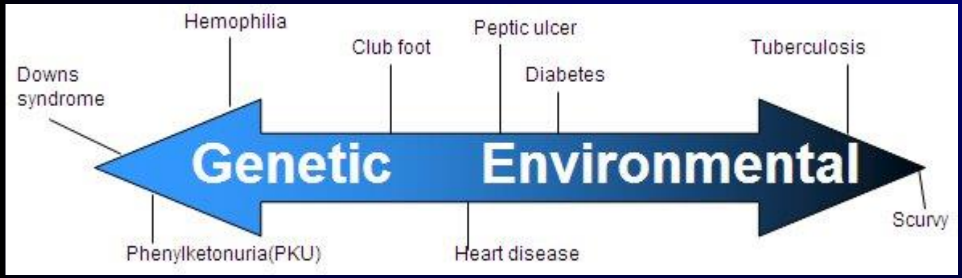




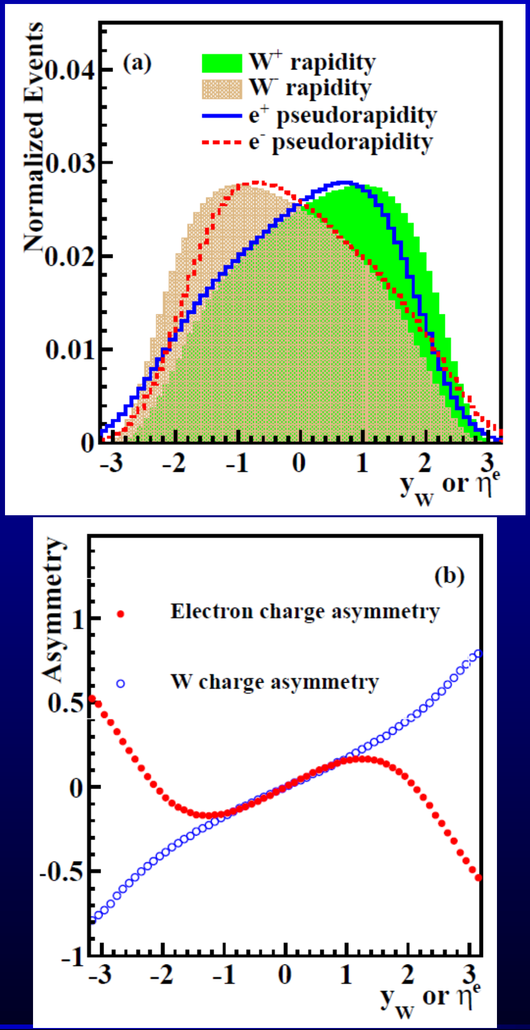
A: Vectors from Birth to Death

- Nature vs. Nurture





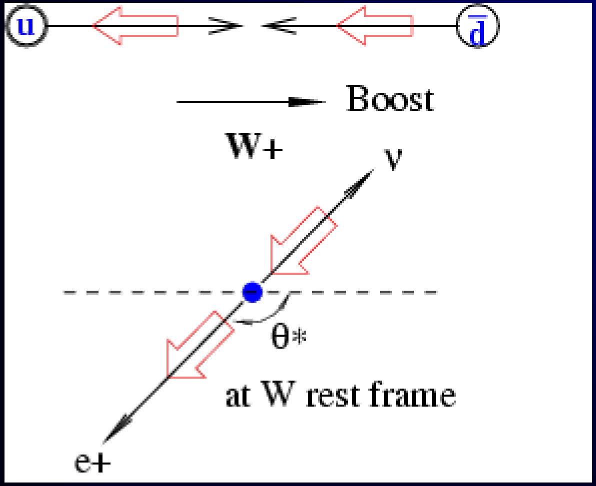
- $p\bar{p} \rightarrow W + X \rightarrow e\nu + X$

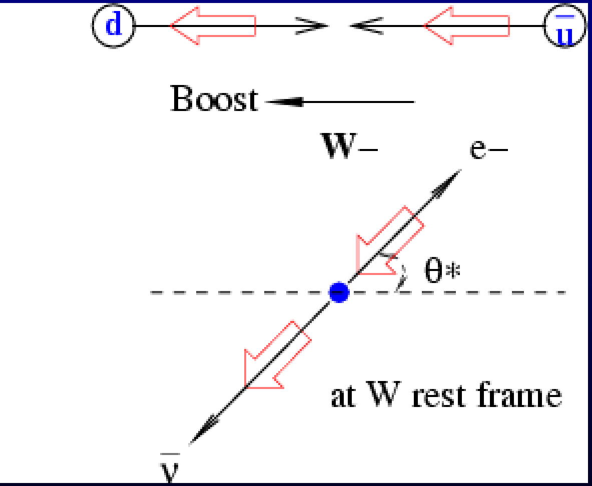


A: Introduction

- *W* **charge asymmetry is sensitive to Parton Distribution Functions (PDFs)**
  - Tevatron is $p\bar{p}$ collider, and $u(\bar{u})$ quark has higher momentum
  - W^+ boosted in p direction, W^- boosted in $\bar{p}$ direction
- **Provides a strong constraint on u and d PDFs**
- **The *W* asymmetry in the leading order parton model is**

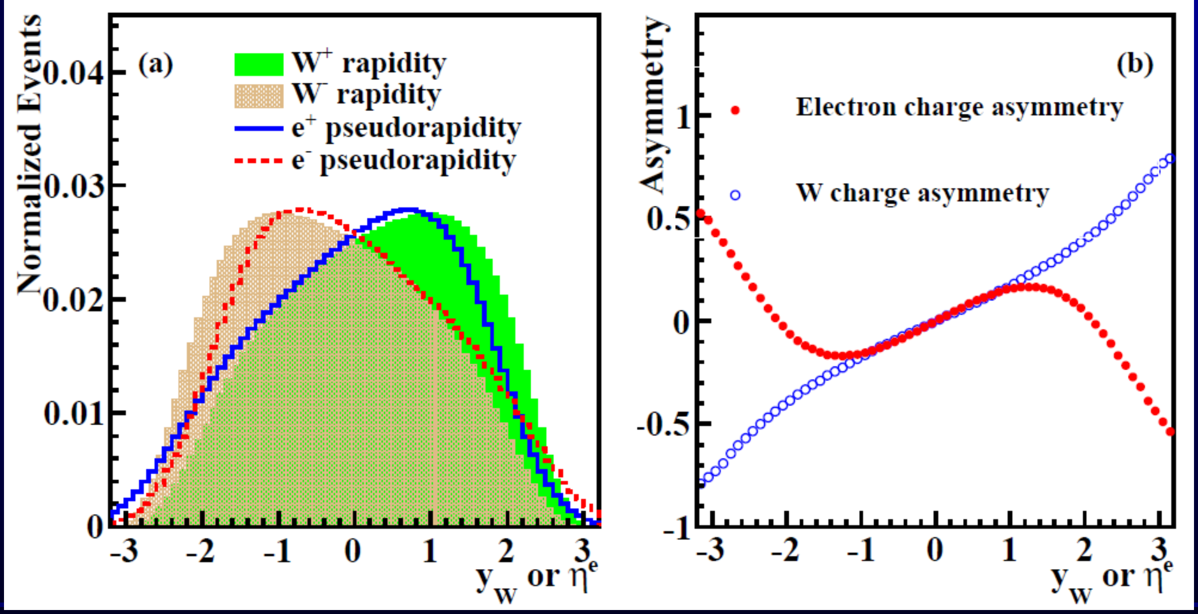
$$A(y_W) = \frac{\frac{d\sigma^+}{dy_W} - \frac{d\sigma^-}{dy_W}}{\frac{d\sigma^+}{dy_W} + \frac{d\sigma^-}{dy_W}} = \frac{u(x_p)\bar{d}(x_{\bar{p}}) - d(x_p)\bar{u}(x_{\bar{p}})}{u(x_p)\bar{d}(x_{\bar{p}}) + d(x_p)\bar{u}(x_{\bar{p}})}$$





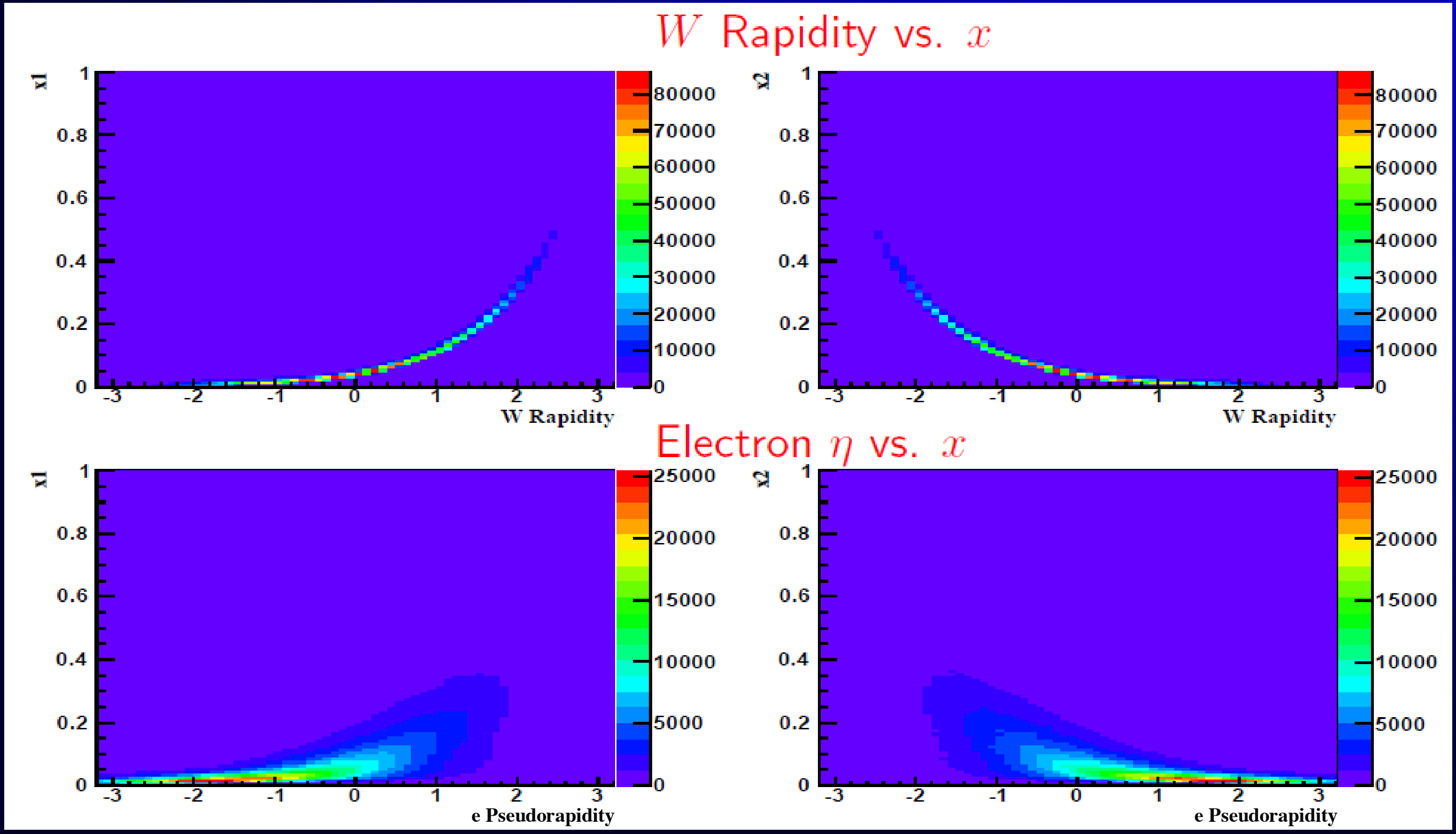
A: Introduction

- **The lepton asymmetry is a convolution of the *W* production asymmetry and the *W V−A* decay**
- **Lepton asymmetry:** More straightforward observable, easier to measure than *W*
- ***W* asymmetry:**
  - Advantage over lepton: Due to convolution, leptons at a specific pseudorapidity (η) originate from a wide range of *W* rapidities, and therefore from a wide range of parton *x* values, making these asymmetries less useful in determining PDFs.
  - Challenge: With unknown neutrino p_Z, difficult to determine the *W* rapidity



A: Introduction

- Asymmetry vs. x : the lepton asymmetry comes from a larger range of parton x values compared with the W asymmetry
- The W asymmetry is more sensitive to the u/d ratio

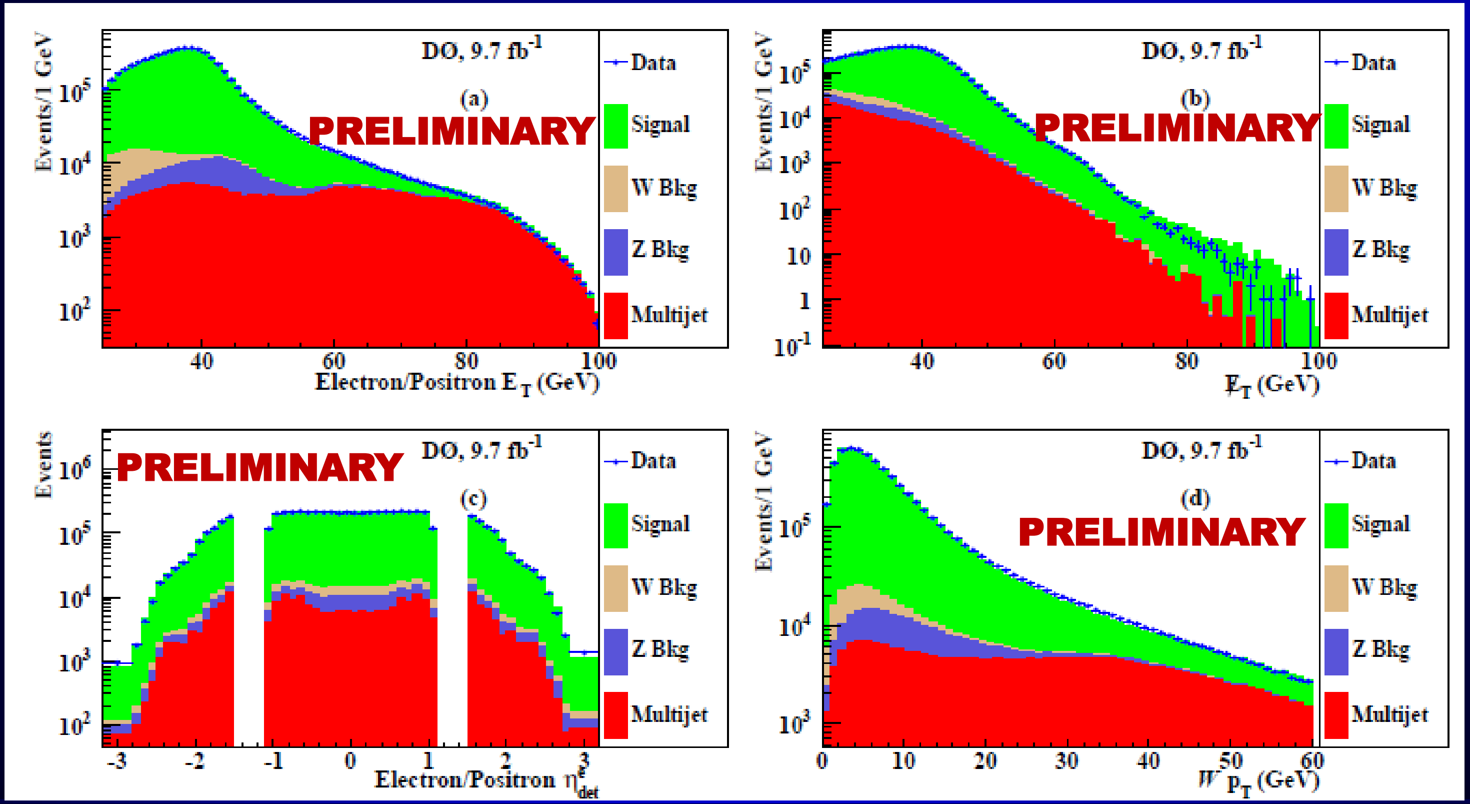


A: Strategy

- Select $W \to e\nu$ candidates from data
- Subtract backgrounds: QCD, $Z \to ee, W \to \tau\nu, Z \to \tau\tau$
- Unfold to remove detector effects
- Use neutrino-weighting method to obtain W rapidity distributions
- Compare corrected asymmetries with theoretical predictions using different PDF sets
- Analysis performed in 5 kinematic bins:
  - Symmetric: $E_T^e > 25\ GeV$, $\not{E}_T > 25\ GeV$; $35\ GeV > E_T^e > 25\ GeV$, $35\ GeV > \not{E}_T > 25\ GeV$; $E_T^e > 35\ GeV$, $\not{E}_T > 35\ GeV$
  - Asymmetric: $35\ GeV > E_T^e > 25\ GeV$, $\not{E}_T > 25\ GeV$; $E_T^e > 35\ GeV$, $\not{E}_T > 25\ GeV$

A: Selection and Backgrounds

- **Event Selection (full data, 9.7 fb^{-1})**
  - Electron: $25 < p_T < 100$ GeV
  - Missing transverse energy > 25 GeV
  - W: $50 < M_T < 130$ GeV
  - Track matching
- **Backgrounds**
  - QCD: 4.0%
  - $Z \rightarrow ee$: 2.6%
  - $W \rightarrow \tau\nu$: 2.2%
  - $Z \rightarrow \tau\tau$: 0.2%

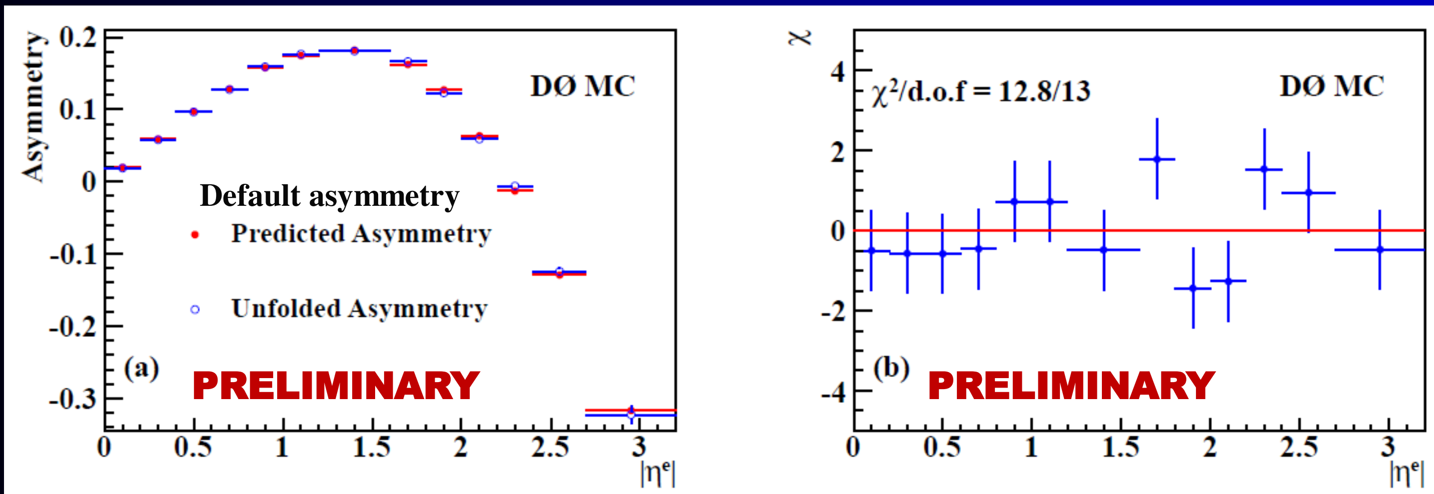


A: Unfolding

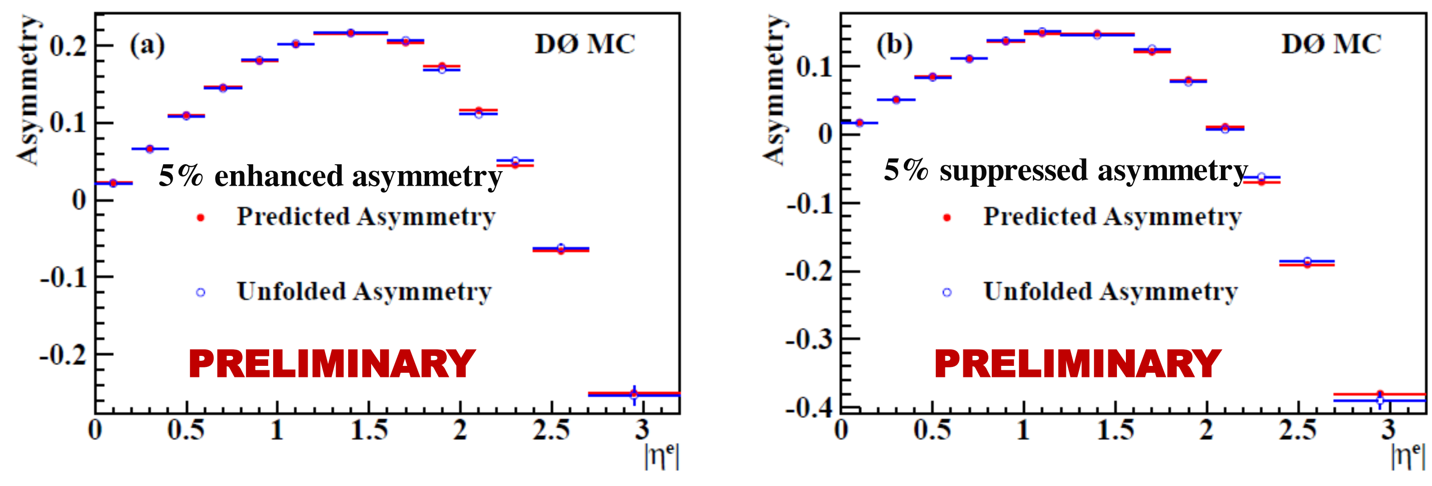
1. **Migration matrix: used to remove detector resolution effects**
   - Electron and positron are expected to have same detector response
   - Study migration matrices for all events ($e^- + e^+$): no input bias
2. **$K^{\pm}_{eff}$: relative efficiency for positrons and electrons**
   - Use $Z \rightarrow ee$ events to study $K^{\pm}_{eff}$ track bias from alignment + solenoid polarity
   - Only study $K^{\pm}_{eff}$ for track cuts, do not expect calorimetry cuts to have such effects
3. **Acc × Eff: to remove kinematic and geometric cut effects**

A: Closure Tests

- Half of MC used for input, half for pseudo-data

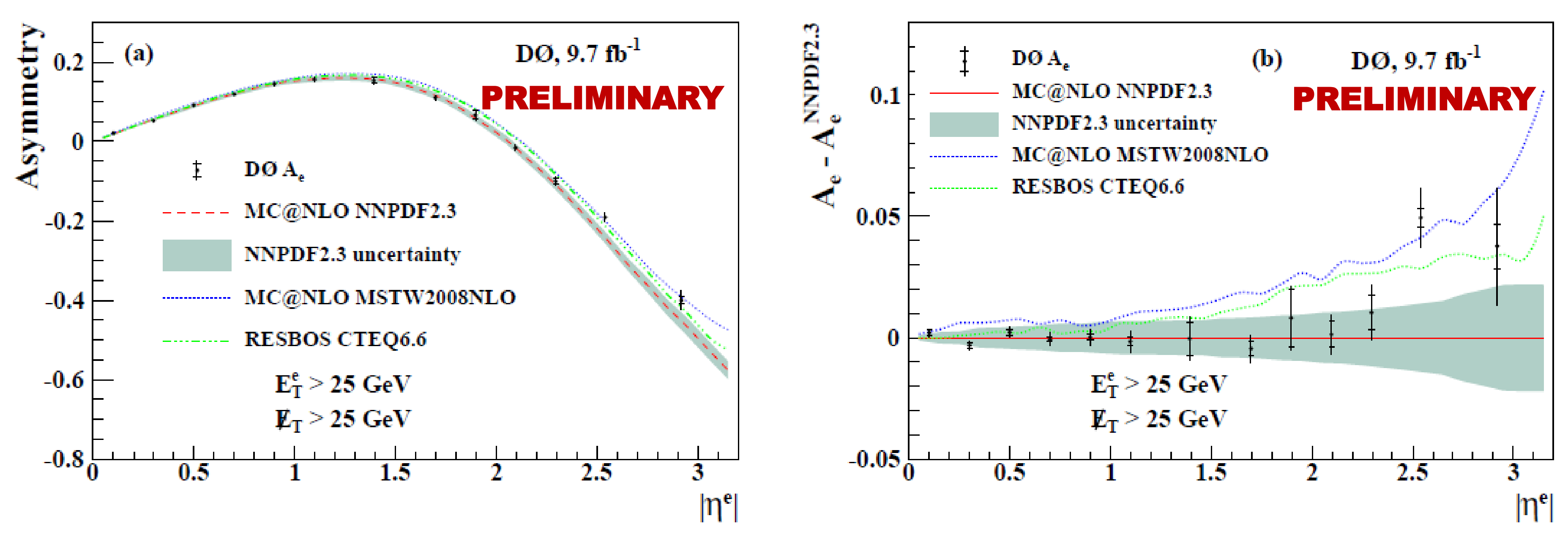


- We get out what we put in



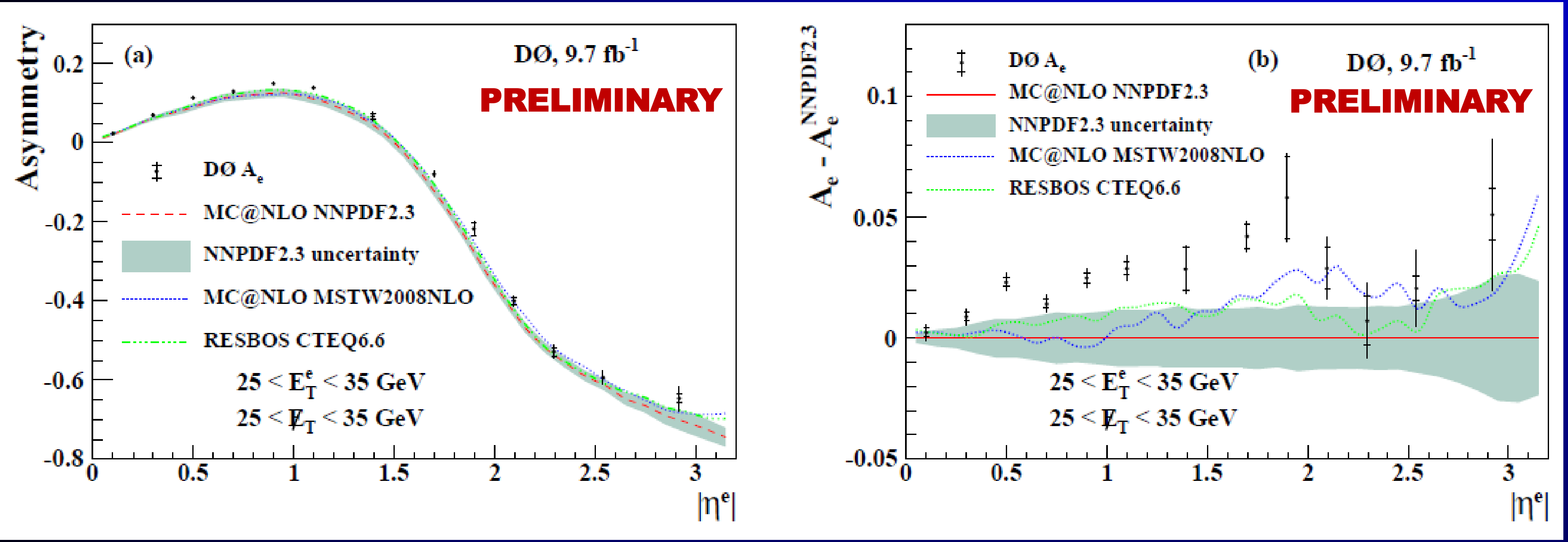
- Unfolding corrections valid for range of asymmetry

A: e Charge Asymmetry Results

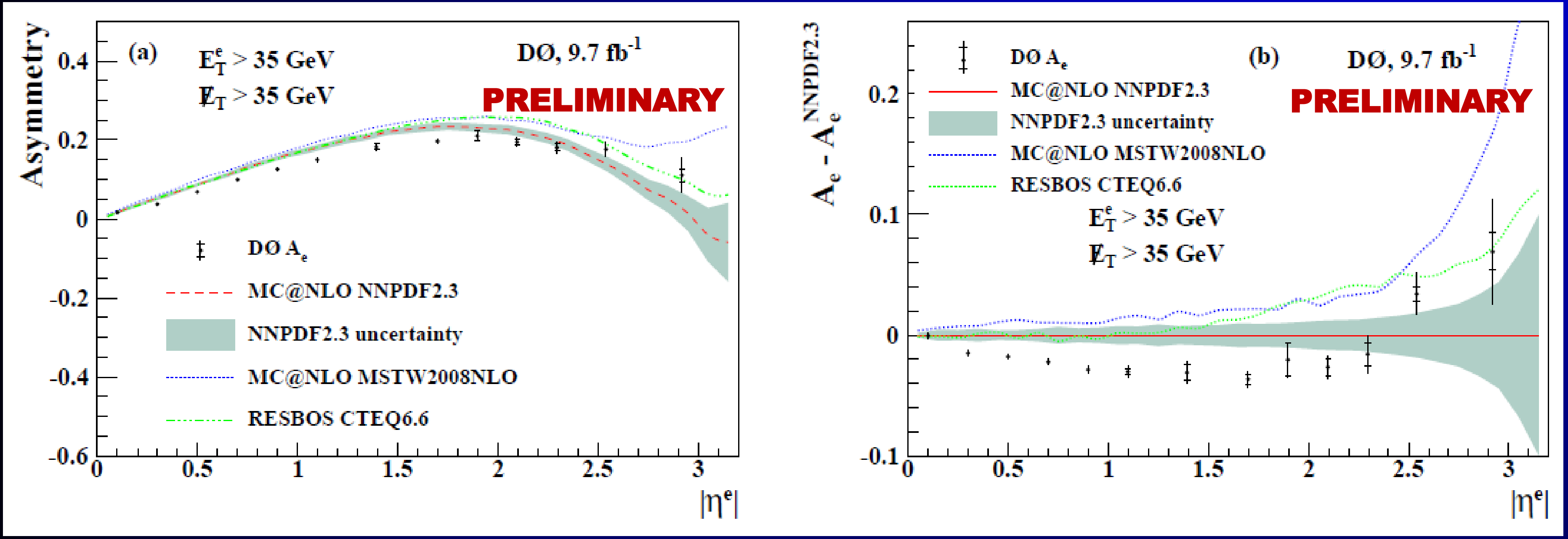


- **These results supersede previous D0 0.7 fb^{-1} measurement**
  - Old result lacked improved calibrations, *the* $K_{eff}^{\pm}$ correction, and additional systematic uncertainties included in the current analysis
- **Submission to PRD very soon**

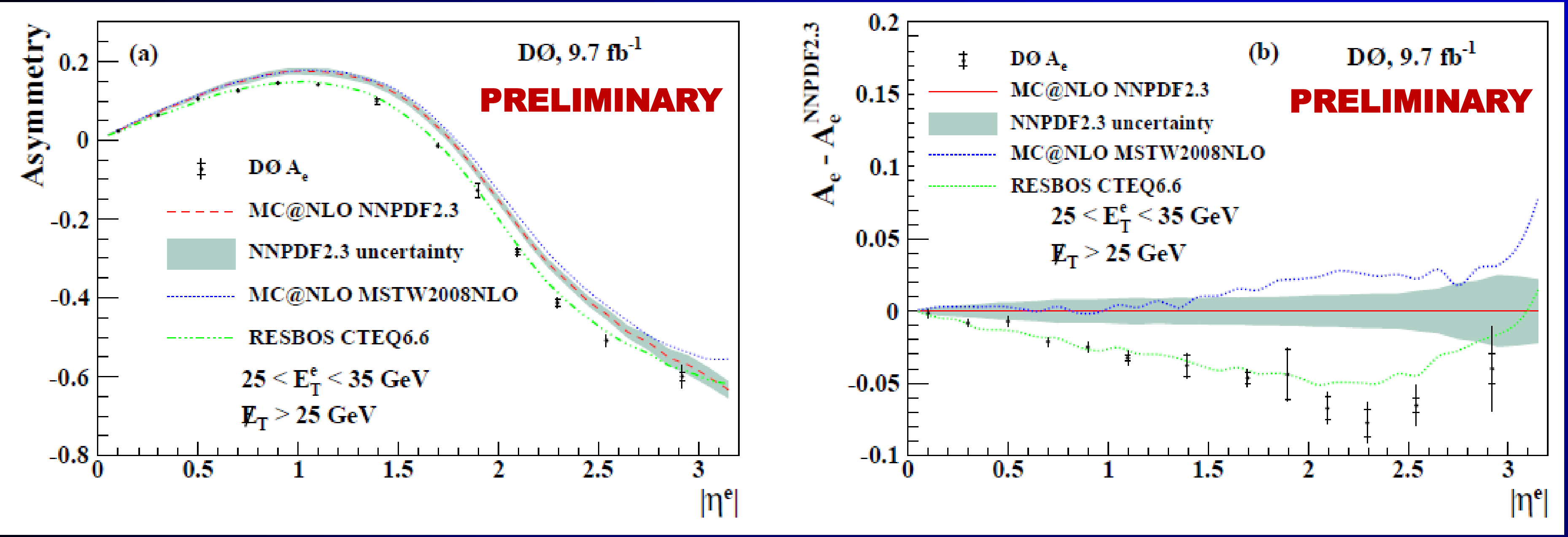
A: e Charge Asymmetry Results



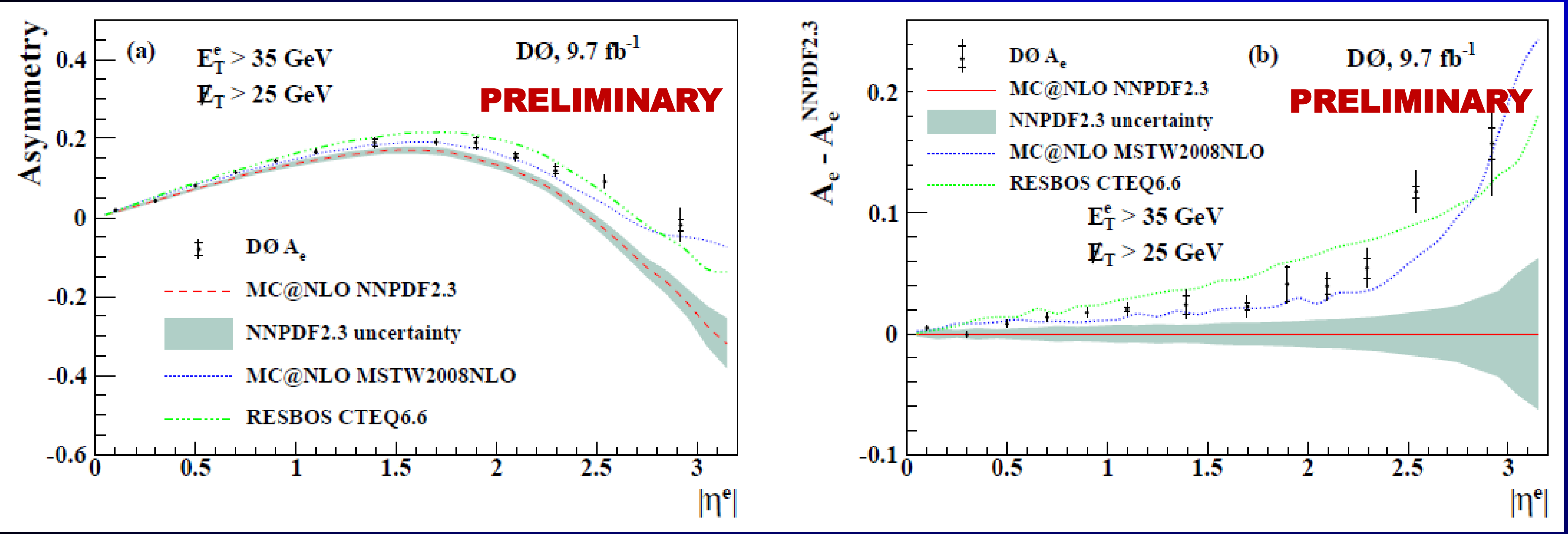
A: e Charge Asymmetry Results



A: e Charge Asymmetry Results



A: e Charge Asymmetry Results



A: Neutrino weighting for W

- **W rapidity:**

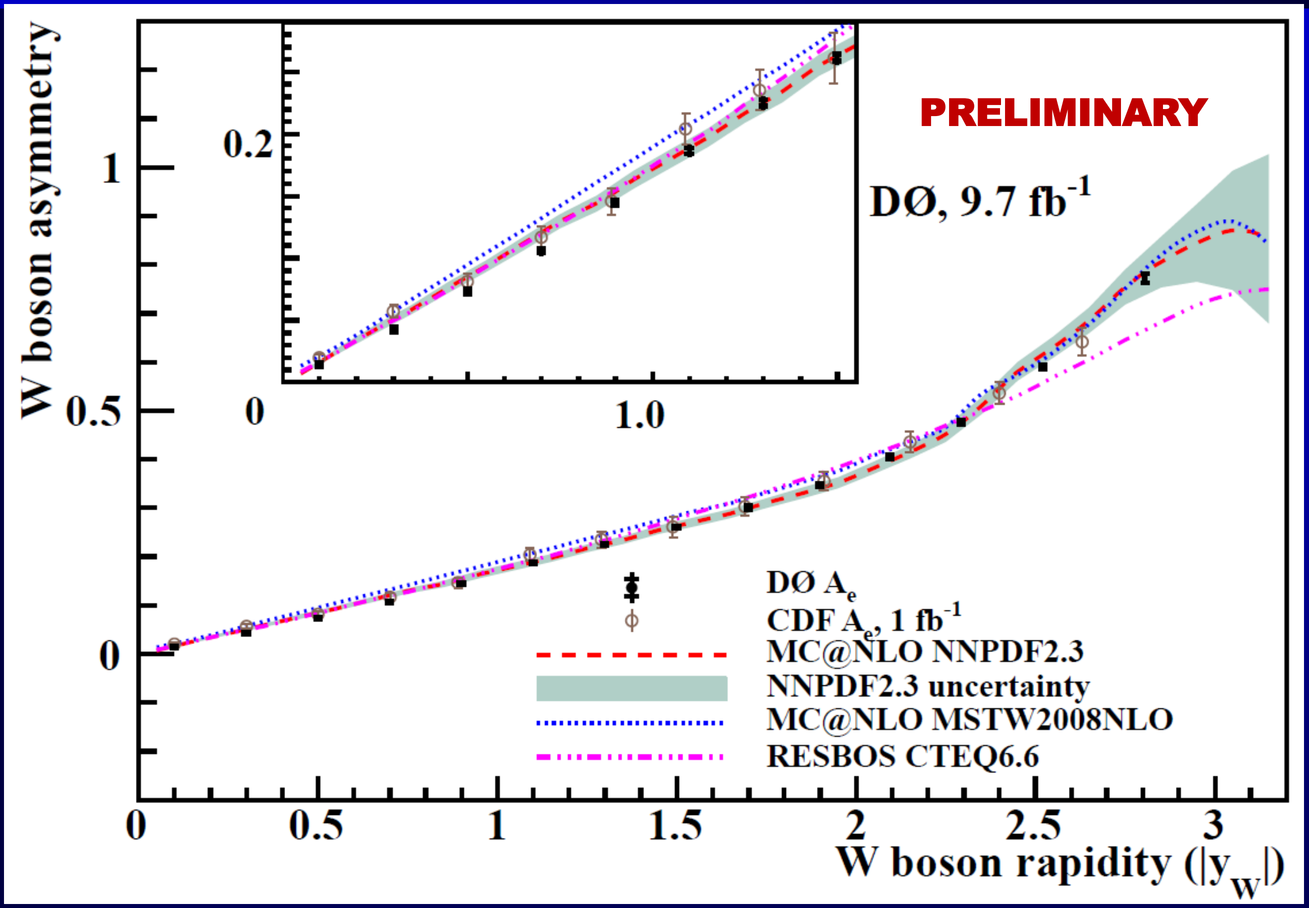
A. Bodek, et. al. PRD 77, 111301(R) (2008)

  - Massive particle rapidity: $y = \frac{1}{2} ln \frac{E+p_Z}{E-p_Z}$
  - Fix M_W to 80.385 GeV, $M_W^2 = (E_l + E_\nu)^2 - \left(\vec{P_l} + \vec{P_\nu}\right)^2$
- **Obtain neutrino p_Z^ν solutions, with given mass of W:**
  - If there are two complex solutions, which means $\not{E}_T$ is not measured properly, we scale the $\not{E}_T$ to set the imaginary part to 0
  - If two solutions, give each solution a weight factor, according to W p_T, Collins angle, and rapidity of W boson:

$$P_\pm\left(\cos\theta^*, y_W, p_T^W\right) = \left(1 \mp \cos\theta^*\right)^2 + Q\left(y_W, p_T^W\right)\left(1 \pm \cos\theta^*\right)^2$$

$$w_{1,2}^{\pm} = \frac{P_\pm\left(\cos\theta_{1,2}^*, y_{1,2}, p_T^W\right) d\sigma^\pm\left(y_{1,2}\right)}{P_\pm\left(\cos\theta_1^*, y_1, p_T^W\right) d\sigma^\pm\left(y_1\right) + P_\pm\left(\cos\theta_2^*, y_2, p_T^W\right) d\sigma^\pm\left(y_2\right)}$$

A: W Charge Asymmetry Result



- **Erratum to PRL 112, 151803 (2014) arXiv:1312.2895**
  - Now employing corrected $K^{\pm}_{eff}$ determination from e charge asymmetry
  - < 2% difference from original publication

A: Summary

- **Measurement of W charge asymmetry in electron channel with DØ RunII full data-set and extended η coverage to 3.2**
  - Most precise measurement of lepton charge asymmetry to date
  - First and most precise direct measurement of W boson production asymmetry from DØ
- **Of benefit to all hadronic physics analyses**
  - Improvement of PDF models in the $x - Q^2$ region of interest for W production at the Tevatron is estimated to reduce the PDF uncertainty in the DØ M_W measurement by approximately 30% (2-3 MeV)

θ_W: EW Mortality Statistics

FERMILAB-PUB-14-288-E

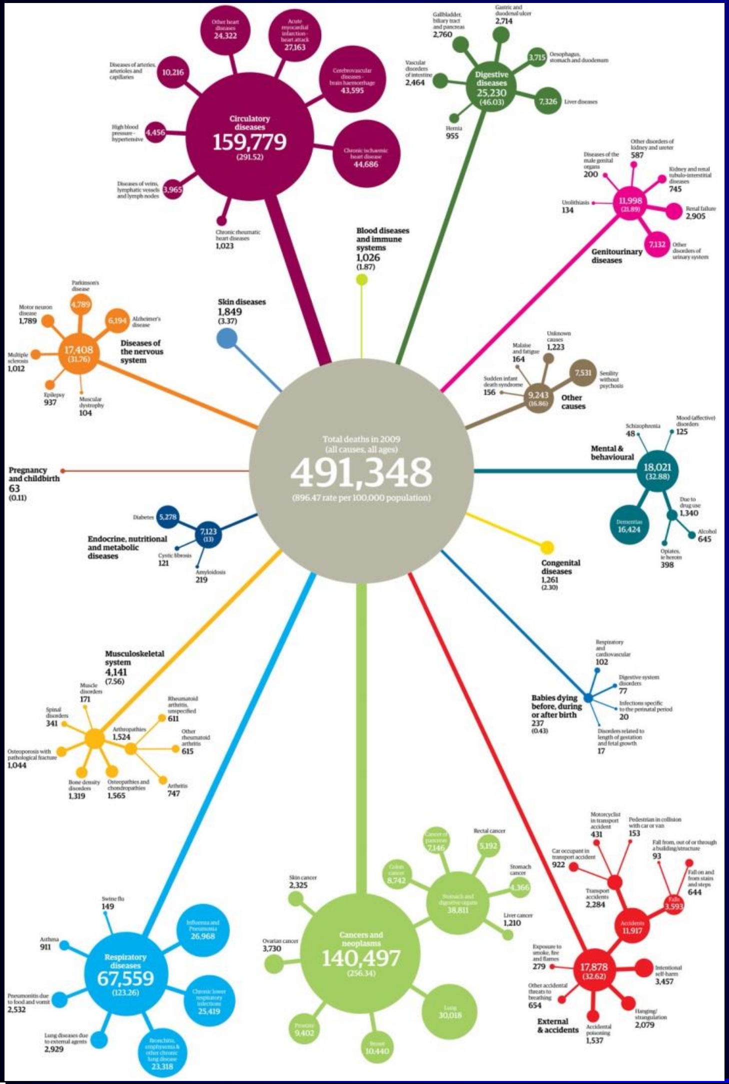
Measurement of the effective weak mixing angle in $p\bar{p} \to Z/\gamma^* \to e^+e^-$ events

V.M. Abazov,[31] B. Abbott,[67] B.S. Acharya,[25] M. Adams,[46] T. Adams,[44] J.P. Agnew,[41] G.D. Alexeev,[31] G. Alkhazov,[35] A. Alton[a],[56] A. Askew,[44] S. Atkins,[54] K. Augsten,[7] C. Avila,[5] F. Badaud,[10] L. Bagby,[45] B. Baldin,[45] D.V. Bandurin,[73] S. Banerjee,[25] E. Barberis,[55] P. Baringer,[53] J.F. Bartlett,[45] U. Bassler,[15] V. Bazterra,[46] A. Bean,[53] M. Begalli,[2] L. Bellantoni,[45] S.B. Beri,[23] G. Bernardi,[14] R. Bernhard,[19] I. Bertram,[39] M. Besançon,[15] R. Beuselinck,[40] P.C. Bhat,[45] S. Bhatia,[58] V. Bhatnagar,[23] G. Blazey,[47] S. Blessing,[44] K. Bloom,[59] A. Boehnlein,[45] D. Boline,[64] E.E. Boos,[33] G. Borissov,[39] M. Borysova[l],[38] A. Brandt,[70] O. Brandt,[20] R. Brock,[57] A. Bross,[45] D. Brown,[14] X.B. Bu,[45] M. Buehler,[45] V. Buescher,[21] V. Bunichev,[33] S. Burdin[b],[39] C.P. Buszello,[37] E. Camacho-Pérez,[28] B.C.K. Casey,[45] H. Castilla-Valdez,[28] S. Caughron,[57] S. Chakrabarti,[64] K.M. Chan,[51] A. Chandra,[72] E. Chapon,[15] G. Chen,[53] S.W. Cho,[27] S. Choi,[27] B. Choudhary,[24] S. Cihangir,[45] D. Claes,[59] J. Clutter,[53] M. Cooke[k],[45] W.E. Cooper,[45] M. Corcoran,[72] F. Couderc,[15] M.-C. Cousinou,[12] D. Cutts,[69] A. Das,[42] G. Davies,[40] S.J. de Jong,[29,30] E. De La Cruz-Burelo,[28] F. Déliot,[15] R. Demina,[63] D. Denisov,[45] S.P. Denisov,[34] S. Desai,[45] C. Deterre[c],[20] K. DeVaughan,[59] H.T. Diehl,[45] M. Diesburg,[45] P.F. Ding,[41] A. Dominguez,[59] A. Dubey,[24] L.V. Dudko,[33] A. Duperrin,[12] S. Dutt,[23] M. Eads,[47] D. Edmunds,[57] J. Ellison,[43] V.D. Elvira,[45] Y. Enari,[14] H. Evans,[49] V.N. Evdokimov,[34] A. Fauré,[15] L. Feng,[47] T. Ferbel,[63] F. Fiedler,[21] F. Filthaut,[29,30] W. Fisher,[57] H.E. Fisk,[45] M. Fortner,[47] H. Fox,[39] S. Fuess,[45] P.H. Garbincius,[45] A. Garcia-Bellido,[63] J.A. García-González,[28] V. Gavrilov,[32] W. Geng,[12,57] C.E. Gerber,[46] Y. Gershtein,[60] G. Ginther,[45,63] O. Gogota,[38] G. Golovanov,[31] P.D. Grannis,[64] S. Greder,[16] H. Greenlee,[45] G. Grenier,[17] Ph. Gris,[10] J.-F. Grivaz,[13] A. Grohsjean[c],[15] S. Grünendahl,[45] M.W. Grünewald,[26] T. Guillemin,[13] G. Gutierrez,[45] P. Gutierrez,[67] J. Haley,[68] L. Han,[4] K. Harder,[41] A. Harel,[63] J.M. Hauptman,[52] J. Hays,[40] T. Head,[41] T. Hebbeker,[18] D. Hedin,[47] H. Hegab,[68] A.P. Heinson,[43] U. Heintz,[69] C. Hensel,[1] I. Heredia-De La Cruz[d],[28] K. Herner,[45] G. Hesketh[f],[41] M.D. Hildreth,[51] R. Hirosky,[73] T. Hoang,[44] J.D. Hobbs,[64] B. Hoeneisen,[9] J. Hogan,[72] M. Hohlfeld,[21] J.L. Holzbauer,[58] I. Howley,[70] Z. Hubacek,[7,15] V. Hynek,[7] I. Iashvili,[62] Y. Ilchenko,[71] R. Illingworth,[45] A.S. Ito,[45] S. Jabeen[m],[45] M. Jaffré,[13] A. Jayasinghe,[67] M.S. Jeong,[27] R. Jesik,[40] P. Jiang,[4] K. Johns,[42] E. Johnson,[57] M. Johnson,[45] A. Jonckheere,[45] P. Jonsson,[40] J. Joshi,[43] A.W. Jung,[45] A. Juste,[36] E. Kajfasz,[12] D. Karmanov,[33] I. Katsanos,[59] M. Kaur,[23] R. Kehoe,[71] S. Kermiche,[12] N. Khalatyan,[45] A. Khanov,[68] A. Kharchilava,[62] Y.N. Kharzheev,[31] I. Kiselevich,[32] J.M. Kohli,[23] A.V. Kozelov,[34] J. Kraus,[58] A. Kumar,[62] A. Kupco,[8] T. Kurča,[17] V.A. Kuzmin,[33] S. Lammers,[49] P. Lebrun,[17] H.S. Lee,[27] S.W. Lee,[52] W.M. Lee,[45] X. Lei,[42] J. Lellouch,[14] D. Li,[14] H. Li,[73] L. Li,[43] Q.Z. Li,[45] J.K. Lim,[27] D. Lincoln,[45] J. Linnemann,[57] V.V. Lipaev,[34] R. Lipton,[45] H. Liu,[71] Y. Liu,[4] A. Lobodenko,[35] M. Lokajicek,[8] R. Lopes de Sa,[45] R. Luna-Garcia[g],[28] A.L. Lyon,[45] A.K.A. Maciel,[1] R. Madar,[19] R. Magaña-Villalba,[28] S. Malik,[59] V.L. Malyshev,[31] J. Mansour,[20] J. Martínez-Ortega,[28] R. McCarthy,[64] C.L. McGivern,[41] M.M. Meijer,[29,30] A. Melnitchouk,[45] D. Menezes,[47] P.G. Mercadante,[3] M. Merkin,[33] A. Meyer,[18] J. Meyer[i],[20] F. Miconi,[16] N.K. Mondal,[25] M. Mulhearn,[73] E. Nagy,[12] M. Narain,[69] R. Nayyar,[42] H.A. Neal,[56] J.P. Negret,[5] P. Neustroev,[35] H.T. Nguyen,[73] T. Nunnemann,[22] J. Orduna,[72] N. Osman,[12] J. Osta,[51] A. Pal,[70] N. Parashar,[50] V. Parihar,[69] S.K. Park,[27] R. Partridge[e],[69]

arXiv:1408.5016v1 [hep-ex] 21 Aug 2014

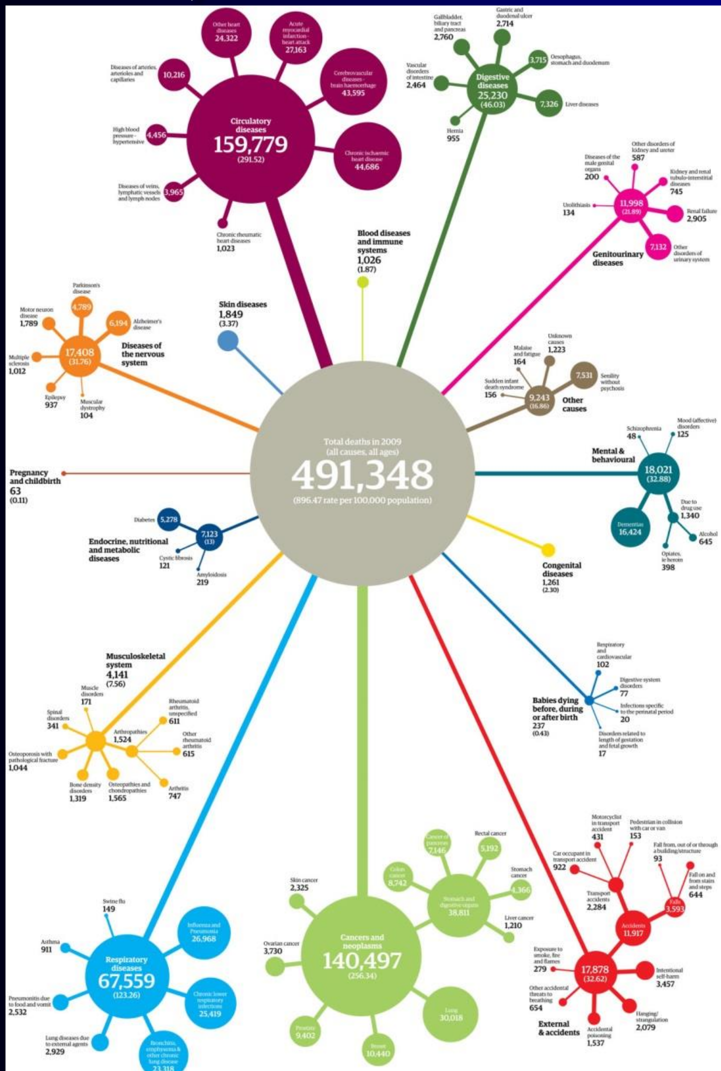
θ_W: EW Mortality Statistics

- **UK, 2013**

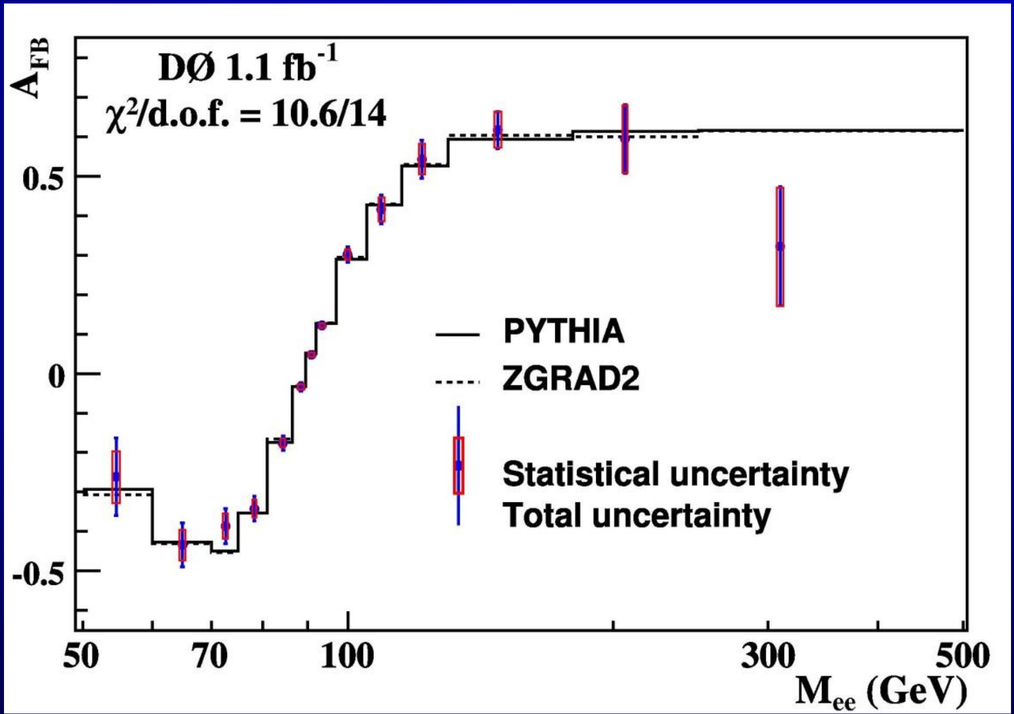


θ_W: EW Mortality Statistics

- UK, 2013



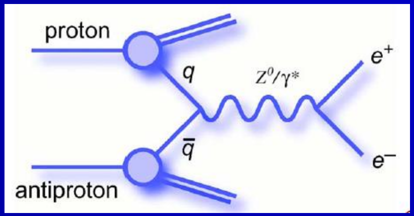
- $Z \rightarrow e^+e^-$
  - PRL 101 , 191801 (2008)



θ_W: Theory

- **Drell-Yan lepton pairs are produced at the Tevatron through**

$$p\bar{p} \rightarrow Z/\gamma^* \rightarrow l^+l^-$$



- **The weak mixing angle can be measured from the forward-backward asymmetry of the polar angle distribution of these Drell-Yan pairs**

$$\underline{q\bar{q} \rightarrow \gamma^* \rightarrow l^+l^-}$$
$$g_V^f = Q_f$$
$$g_A^f = 0$$

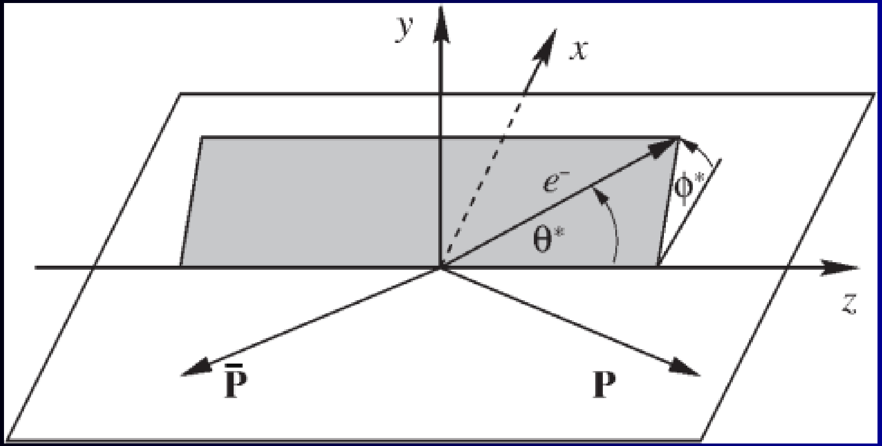
Born level couplings

$$\langle \bar{f} | (g_V + g_A\gamma^5)\gamma^\mu | f \rangle$$

$$\underline{q\bar{q} \rightarrow Z \rightarrow l^+l^-}$$
$$g_V^f = I_3 - 2Q_f sin^2\theta_W$$
$$g_A^f = I_3$$

- $I_3, sin^2\theta_W$ **couplings altered by weak radiative corrections**
  - Multiplicative factor of a few %
  - Gives effective $sin^2\theta_W$ coupling $\rightarrow sin^2\theta_{eff}^l$

θ_W: Theory



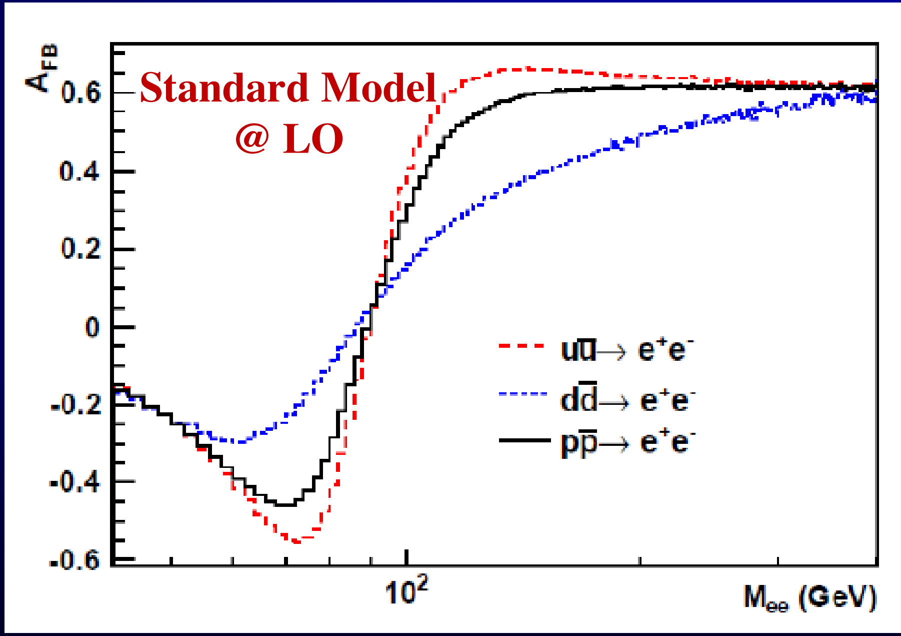
- **Measure $l^- l^+$ angular distribution in the Collins-Soper rest frame of the boson. Polar angle, θ^*, of the l^- is defined relative to the direction of the incoming quark**
  - Forward: $cos\theta^* > 0$, Backward: $cos\theta^* < 0$

- $dN/d\Omega \propto 1 + cos^2\theta^* + A_4 cos\theta^*$
  - All coefficients† but A_4 vanish as $P_T \to 0$
- **$A_4 cos\theta^*$: parity violating, from interference of vector and axial vector currents**
  - Sensitive to $sin^2\theta_W$ through Z self-interference: $(1 - 4|Q_l|sin^2\theta_W)(1 - 4|Q_q|sin^2\theta_W)$

†@ NLO QCD: $dN/d\Omega = 1 + cos^2\theta^* + A_0(1 - 3cos^2\theta^*)/2 + A_1 sin2\theta^* cos\phi + A_2(sin^2\theta^* cos2\phi)/2 + A_3 sin\theta^* cos\phi + A_4 cos\theta^* + A_5 sin^2\theta^* sin2\phi + A_6 sin2\theta^* sin\phi + A_7 sin\theta^* sin\phi$

θ_W: Strategy

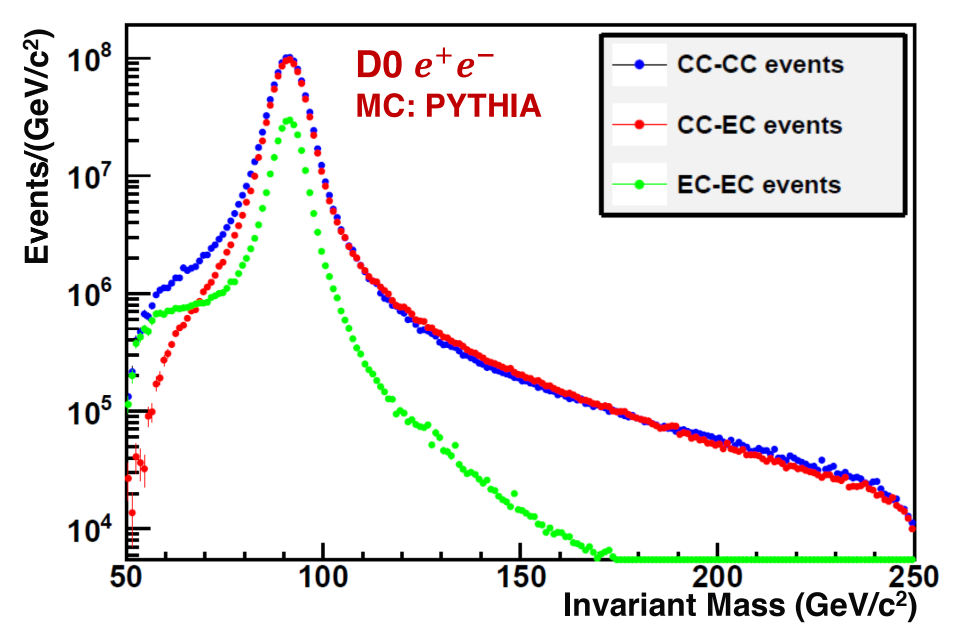
- **Measure A_{FB} in bins of lepton pair invariant mass**
- **Produce Monte Carlo $A_{FB}(M, sin^2\theta_W)$ templates**
- **Perform full corrections to data and simulation**
  - Background subtractions
- **Extract $sin^2\theta_W$ by a χ^2 comparison between data and MC**



θ_W: Event Selection

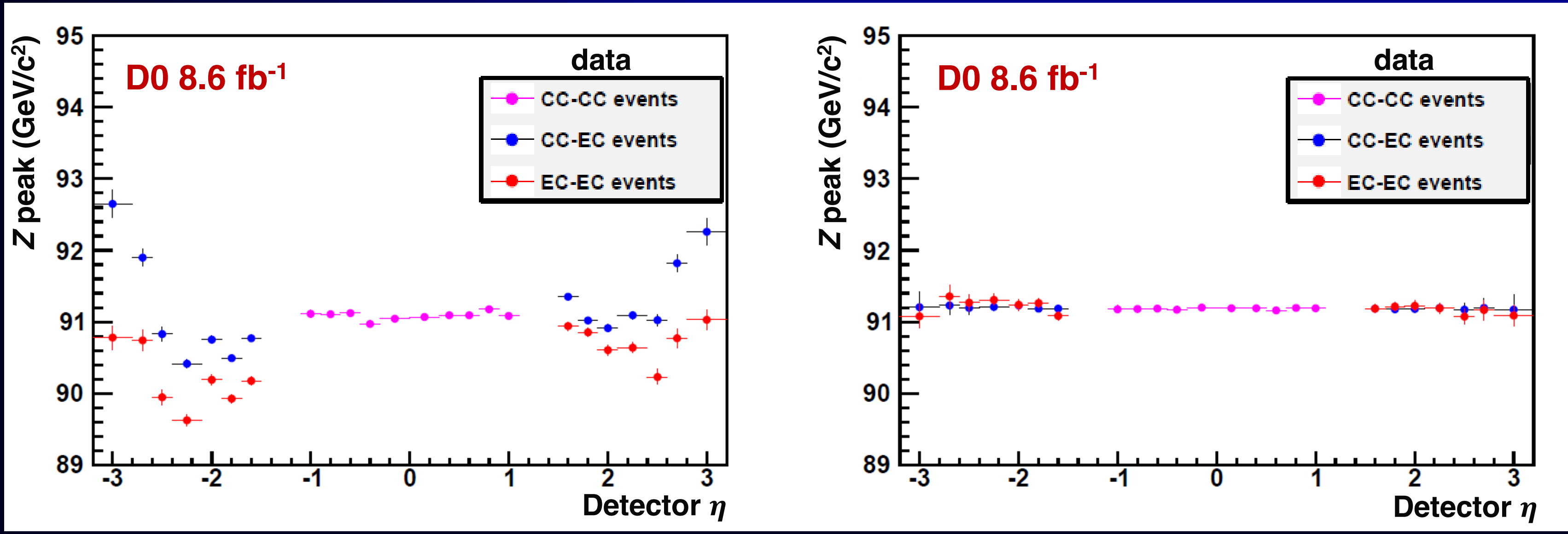
- **Full D0 RunII dataset: 9.7 fb^{-1}**
- **Two high-P_T electrons: $P_T > 25$ GeV**
  - Central and endcap calorimeters (CC,EC)
- **Tight track requirements**
- **Mass distribution: $M > 50$ GeV**
  - $sin^2\theta^l_{eff}$ from $75 < M < 115$ GeV
- **85% increase in statistics**
  - Extend to $|\eta| < 1.1, 1.5 < |\eta| < 3.2$
  - Include EC-EC events
  - Include electrons near calorimeter module (phi-mod) boundaries
  - Track reconstruction improvements
- **560,267 events**
- **Low QCD backgrounds (EW negl.)**
  - CC-CC: 0.4%; CC-EC,EC-EC: < 4%
- **MC: PYTHIA, CTEQ6L1**

- CC-CC: both electrons in the central calorimeter
- CC-EC: one electron in the central calorimeter, the other in an endcap
- EC-EC: both electrons in the endcap calorimeters



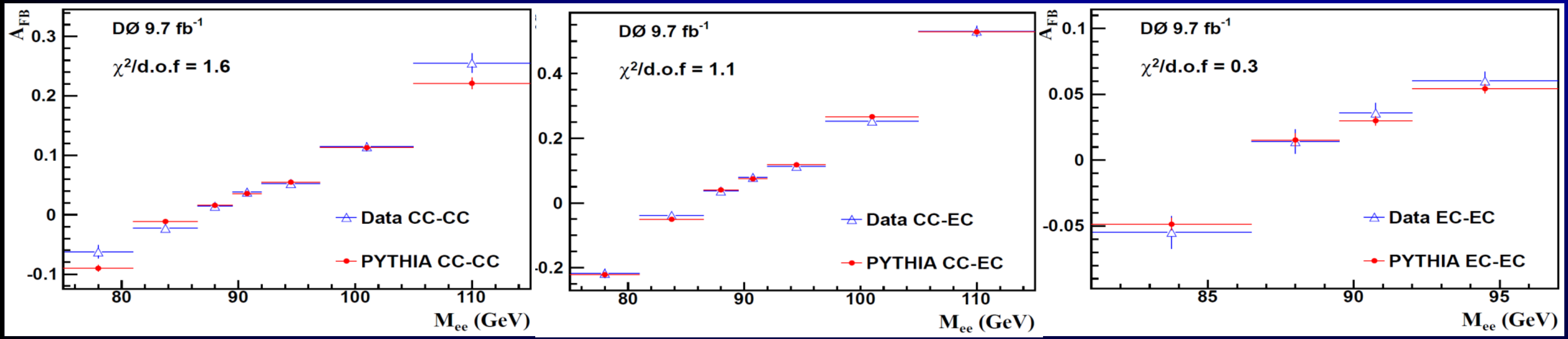
θ_W: Energy Calibration

- **Global energy scale modeling in previous analysis**
  - Shape dependence inadequate for different detector responses of extended acceptance regions
- **New method corrects energy as a function of L_{inst} first, then η_{det}**
  - *Z* mass peak scaled to LEP value (91.1875 GeV) in each bin
  - Separate calibrations for data and MC
- **After calibration, mass peak L_{inst} dependence negligible, η_{det} dependence reduced from 2 GeV to 100 MeV (data), 10 MeV (MC)**



θ_W: $sin^2\theta_W$ Extraction

- **Raw A_{FB} measurement is compared to reweighted MC A_{FB} templates corresponding to different $sin^2\theta_W$ values**
  - Different $sin^2\theta_W$ predictions obtained by reweighting generator level 2D $(M_{Z/\gamma^*}, cos\theta^*)$ distribution of default MC ($sin^2\theta_W = 0.232$)
  - Done separately for CC-CC, CC-EC, EC-EC events, and for RunIIa (1.1 fb^{-1} low L_{inst}) and RunIIb (8.6 fb^{-1} high L_{inst}) running periods



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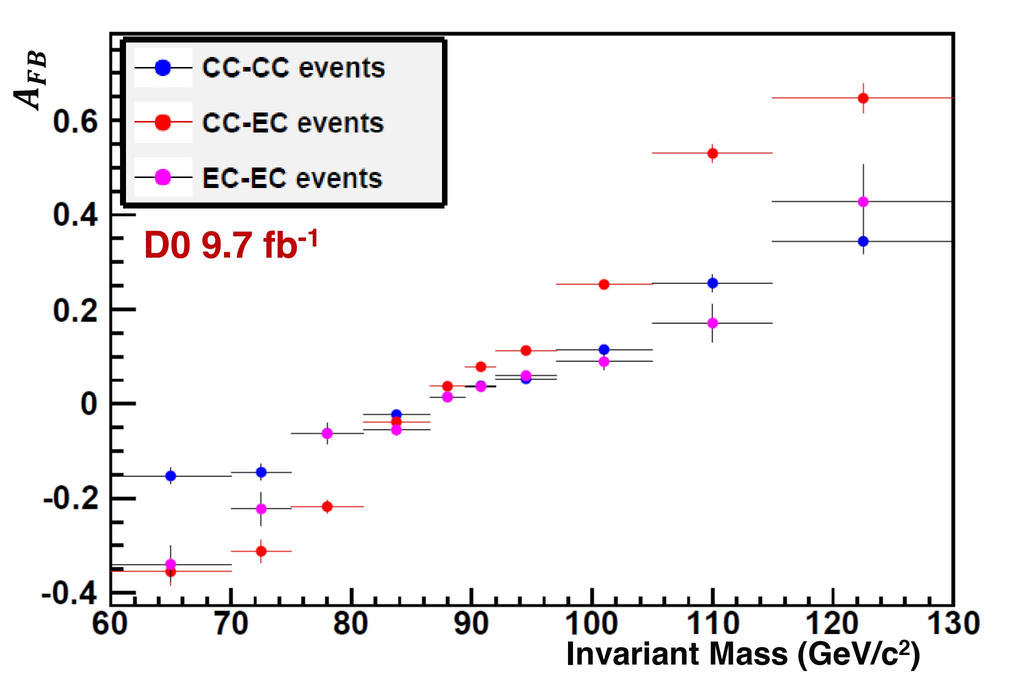

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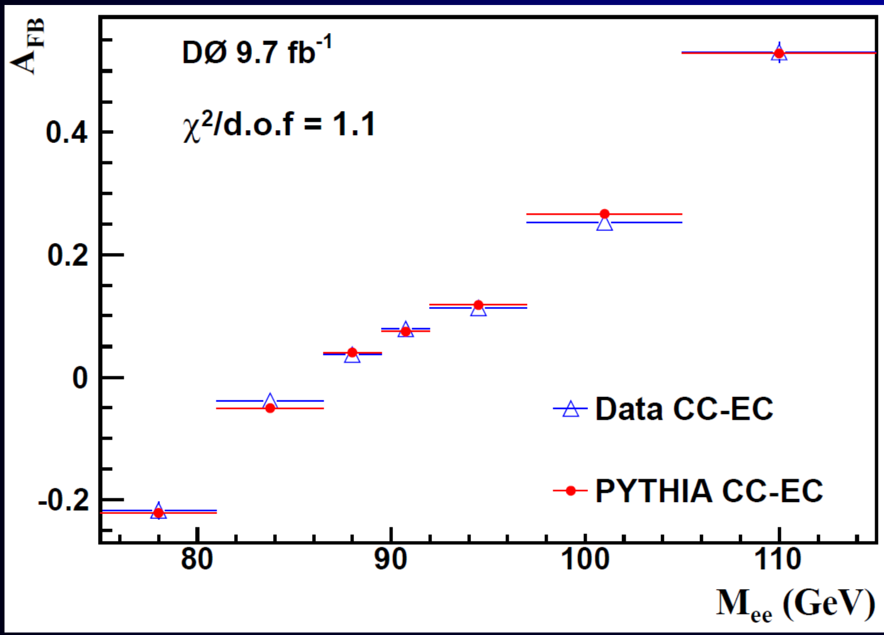
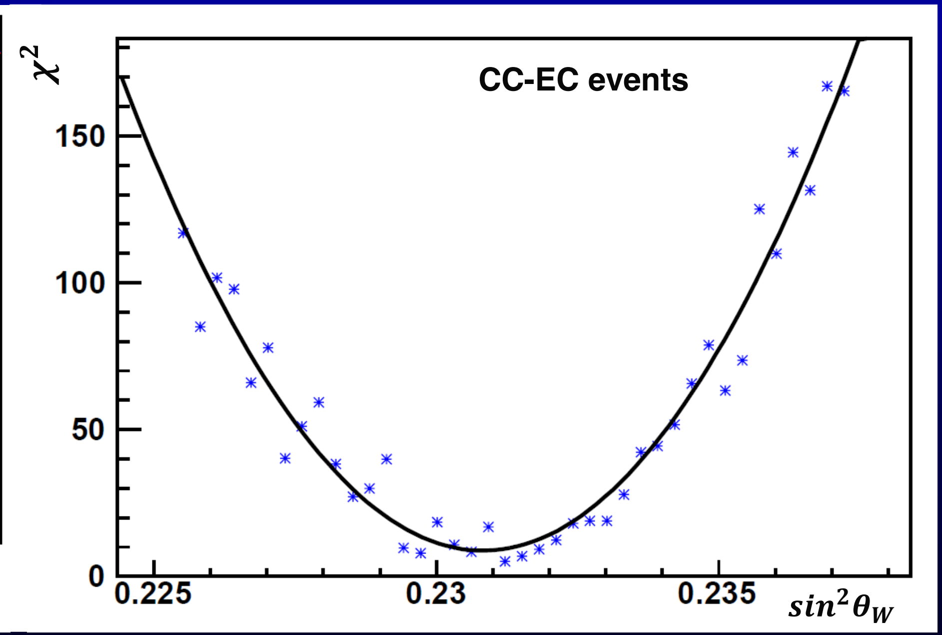




θ_W: Results

	CC-CC	CC-EC	EC-EC	Combined
$\sin^2\theta_W$	0.23140	0.23142	0.22986	0.23138
Statistical	0.00116	0.00047	0.00276	0.00043
Systematic	0.00009	0.00009	0.00019	0.00008
Energy Calibration	0.00003	0.00001	0.00004	0.00001
Energy Smearing	0.00001	0.00002	0.00013	0.00002
Background	0.00002	0.00001	0.00002	0.00001
Charge Misidentification	0.00002	0.00004	0.00012	0.00003
Electron Identification	0.00008	0.00008	0.00005	0.00007
Total	0.00116	0.00048	0.00277	0.00044
PDF unc.				0.00017

$$sin^2\theta_W = 0.23138 \pm 0.00043 \pm 0.00008 \pm 0.00017$$

(stat) (syst) (PDF)

In SM context, with on-shell renormalization scheme, modified ResBos NLO correction

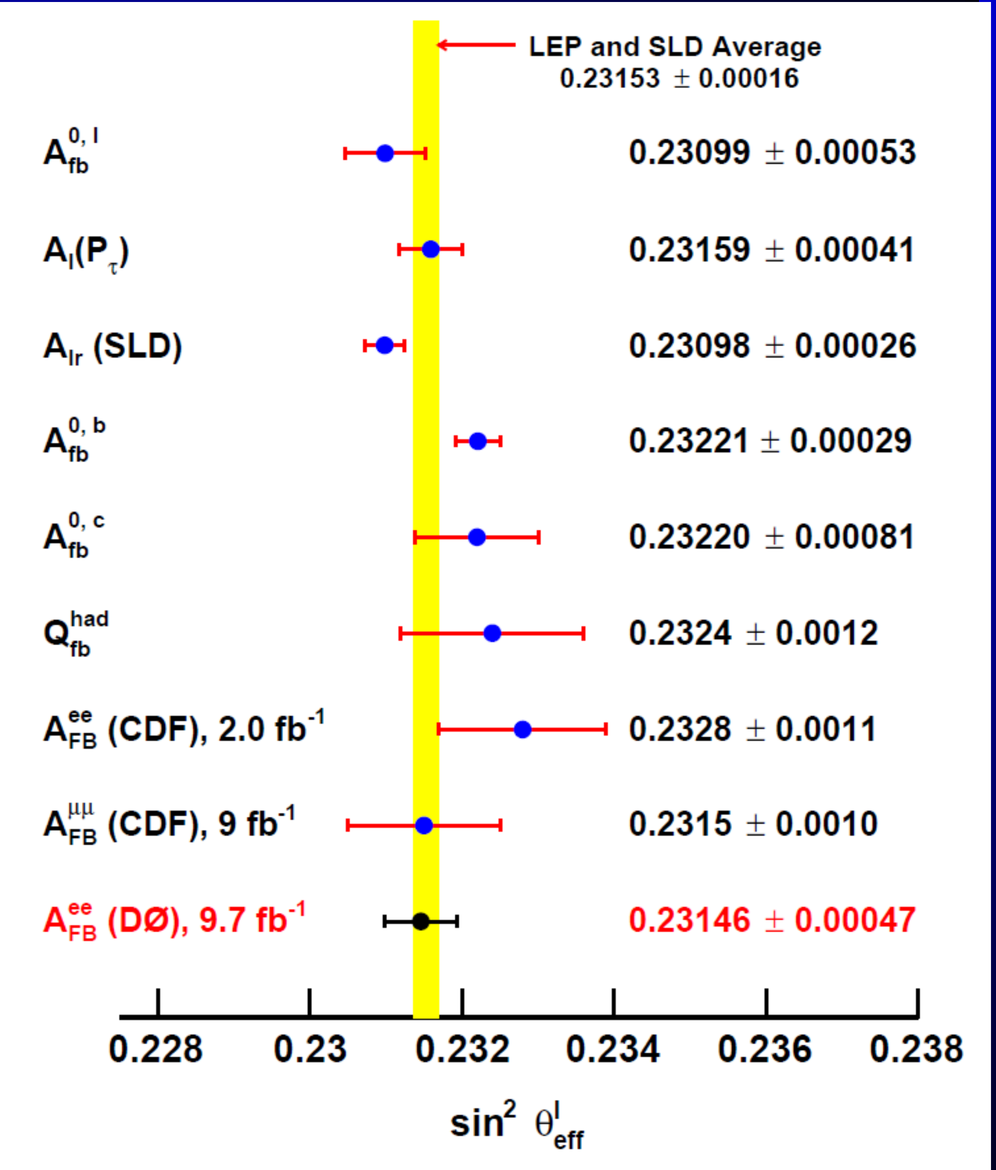
$$\boxed{sin^2\theta^l_{eff} = 0.23146 \pm 0.00047}$$

(thanks to Willis Sakumoto for help)

World's Best From Hadron Collider & from Light Quark Interactions

θ_W: Summary

- **D0 9.7 fb^{-1} :**
  $sin^2\theta^l_{eff} = 0.23146 \pm 0.00047$
  - Submitted to PRL 8/21/14, arXiv:1408.5016
- **World's best from hadron collider**
- **PRD with full A_{FB} and coupling details in preparation**
  - Including indirect M_W determination



New Members of $\Phi^* A\ \theta_W$

- *Scholarship*
  - $\boldsymbol{\phi^*}$: 10/30/14 Submitted to Phys. Rev. D arXiv:1410.8052
  - $\boldsymbol{A}$: 04/18/14 Phys. Rev. Lett 112, 151803 (2014) arXiv:1312.2895
    Submission of electron charge asymmetry to PRD imminent
  - $\boldsymbol{\theta_W}$: 08/22/14 Submitted to Phys. Rev. Lett. arXiv:1408.5016
- *Leadership*
  - $\boldsymbol{\phi^*}$: New high-precision observable, first ever transverse momentum results in off-peak regions
  - $\boldsymbol{A}$: Highest precision W asymmetry results, and extended to higher η
  - $\boldsymbol{\theta_W}$: World's best result from hadron collider and light quark interactions
- *Service*
  - Data can be used to improve PDF sets, benefiting the entire field, e.g. potential for significant improvement of M_W uncertainties

Future Members of $\Phi^* A\ \theta_W$

Class of 2015

- Z Boson Rapidity
- Z Boson A_{FB}, electron channel PRD
- Z Boson A_{FB}, muon channel
- Z Boson Angular Coefficients